Final Report

Cleaning of Pipelines for Abandonment

Tamer Crosby, Desiree Joe, Amanda Prefontaine and Haralampos Tsaprailis

Alberta Innovates - Technology Futures

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(PTAC)

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List of Acronyms

AER	Alberta Energy Regulator
AITF	Alberta Innovates - Technology Futures
APB	Acid Producing Bacteria
APHA	American Public Health Association
ASTM	American Society for Testing and Materials
BART	Bacterial Activity Reaction Test
CEPA	Canadian Energy Pipeline Association
CSA	Canadian Standards Association
EC_{50}	Half Maximal Effective Concentration
EDRO	Extended Diesel Range Organics
EDS/EDX	X-Ray Spectroscopy
EPA	Environmental Protection Agency
EPH	Extractable Petroleum Hydrocarbons
GPA	Gas Processors Association
GRO	Gasoline Range Organics
HAB	Heterotrophic Aerobic Bacteria
IC_{50}	Half Maximal Inhibitory Concentration
ICP-MS	Inductively Coupled Plasma Mass Spectrometers
LC_{50}	Half Maximal Lethal Concentration
MIC	Microbiologically Influenced Corrosion
NEB	National Energy Board
NORMs	Naturally Occurring Radioactive Materials
OWA	Orphan Well Association
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyls
PTAC	Petroleum Technology Alliance Canada
SRB	Sulfate Reducing Bacteria
TIC	Total Inorganic Carbon
TOC	Total Organic Carbon
TPH	Total Petroleum Hydrocarbons

TSS	Total Suspended Solids
UDC	Under Deposit Corrosion
UOP	Universal Oil Products
XES	X-ray Emission Spectroscopy
XRD	X-Ray Diffraction

Executive Summary

As the pipeline infrastructure grows and ages across Canada, abandonment and/or discontinuation of pipelines may increase as well. The process of abandonment/discontinuation needs to be properly handled and executed in order to minimize or eliminate any potential related issues. Communities' stakeholders have raised concerns about the safety of the pipeline abandonment process and about the related long term effects, especially in agricultural areas. For pipelines abandoned in place, the issue of cleanliness is a crucial one and of major concern from environmental and economic standpoints. An abandoned pipeline will inevitably corrode and could lose structural integrity posing the risk of releasing any residual contaminants into the surrounding soil and groundwater. Therefore, assessing the effectiveness of cleaning technologies for pipelines and investigating residual contaminants and methods to detect them are crucial topics that need to be properly addressed.

This study covers the requirements of PTAC Pipeline Abandonment Research Steering Committee (PARSC): PARSC 004 – Cleaning Methods for Abandoned Pipeline and PARSC 005 – Standard Pipeline Products List and Detection of Residual Contamination in Abandoned Pipelines. The two main areas that this study covers are 1) the effectiveness of cleaning methods (mechanical and chemical methods) for pipeline abandonment; and 2) potential residual contaminants and methods to detect them. In addition, the study reviews federal and provincial regulations and standards that address the subject of abandonment/deactivation, and presents some of the current industry abandonment guidelines and programs.

The scope of this report is focused on oil and gas transmission pipelines in Canada. The main research methodologies were direct engagements with stakeholders and literature searches. The latter includes industry reports, conference and journal technical papers, government agencies publications, and other open sources.

From the engagement surveys, it was found that most of the pipeline operators do not have detailed guidelines for abandonment with the exception of few companies that are currently undergoing major abandonment/decommissioning projects. This is due to the fact that, to date, pipeline abandonment has not been commonly occurring in transmission pipeline companies.

Mechanical cleaning suppliers have their own recommendation or guidelines for pipeline abandonment and these are centered on proper pig selection. Upon request, suppliers readily provide pig selection criteria to operating companies interested in cleaning a pipe for the purposes of abandonment. The same is also true for chemical suppliers who would recommend different chemical cleaning products based on the history of the pipeline, commodity, and purpose of cleaning, among others. Moreover, the interview with the provincial and federal regulators confirmed that very few regulations exist regarding cleaning procedures for abandonment and no criteria exist on the acceptable levels of residual contaminants. The CSA standard Z662 was found to be used by different provinces and companies as minimum requirements that must be met.

In crude oil pipelines, the main contaminants are sludge deposits. Sludge deposits vary in composition from one line to another. In general, O is the most present element (37.1- 54.9 %) followed by Si (14.4 - 31.3 %) and then Fe (3.4 - 27.34 %). Other elements such as C and S also may exist, but to a lesser percentage. In gas pipelines, the main contaminants are black powder, NORMs, hydrocarbons, and PCBs. Checking the level of residues left in the pipeline after cleaning is essential to verify the effectiveness of the cleaning program. The identification of test methods for residual contaminant has provided direction for field testing that could be performed as well as a basis for establishing a list of contaminants that could be regulated. The existence of commercial field testing instruments will render on-site sampling and testing more feasible and cost effective.

Given that pipeline abandonment is a complex process with multiple factors to consider; it would be advisable to develop recommended guidelines for cleaning abandoned pipelines. The recommended guidelines, which can eventually be transitioned into a standard, would be extremely beneficial to the industry and pipeline operators, as well as the regulators and other stakeholders (e.g. land owners), as it will aim to standardize the process of pipeline abandonment. Meanwhile, more recommendations are discussed at the end of this study.

1 INTRODUCTION

Production of petroleum products is forecasted to increase in Canada in response to growing global energy demand and as a result of new technologies that have made the production of natural gas from shale deposits and the extraction of bitumen from oil sands resources more feasible and economical. The construction of new pipelines will be required to allow increased petroleum production from western Canada to reach domestic and export markets in eastern Canada, the United States of America, and Asia (Godin, 2014). The installation of new lines might prompt an increase in pipeline abandonment, deactivation, or replacement programs.

At the end of 2012, the AER data tallied 415,152 km of pipelines within the province of Alberta. Of Alberta's total pipeline inventory, 60.3 % carries natural gas, 14.8 % carries oil effluent (mixed oil, gas, and water production from an oil well; also known as multiphase), 5.9 % carries oilfield water, 4.9 % carries crude oil, 5.4 % carries sour gas (natural gas with hydrogen sulphide concentrations greater than 1 %), and 8.7 % carries other substances (Alberta Energy Regulator, 2013). Most of the pipelines in the province are small diameter pipes with an outside diameter of 168.3 mm (6 inches) or smaller with transmission pipelines consisting of only 2 % of the total pipeline inventory regulated by the AER. Although this report focuses on transmission pipelines, it is worth noting that about 17 % of the AER inventory is discontinued or abandoned.

Typically, the abandonment of a pipeline happens when a company decides to remove the pipeline permanently from service. If the removal from service is temporary, with the intent of reactivating the line, the action is referred to as deactivation or discontinuation. The terms deactivation and discontinuation are used for pipelines under the jurisdictions of the NEB and the AER, respectively. An abandoned pipeline may be removed from the ground, or it may be cleaned, treated, and left in place (Canada. National Energy Board, Regulating Pipeline Abandonment, June 2011). The choice for pipeline removal or abandonment in place depends on different factors such as future development plans for the land, impact of disturbing the landscape, and cost of removal, among others. Therefore, it is very important to gather all the necessary and relevant information before developing and proceeding with an abandonment plan.

Communities' stakeholders have raised concerns about the safety of the process of pipeline abandonment and the related long term effects, especially in agricultural areas (Godin, 2014).

For pipelines that will be abandoned in place, the issue of pipe cleanliness is related to corrosion and the creation of water conduits. Eventually, the pipe will corrode and become perforated and, aided by the destructive forces of the freeze-thawing of infiltrated water, the structural integrity of the abandoned pipeline will degrade. The problem then rises when the life of the contaminants is longer than the rate of deterioration, which imposes a possibility for leakage of contaminant into the ground. Subsequently, it is critical to ensure that an abandoned pipe is thoroughly cleaned to minimize the amount of remaining residues that could impact the environment.

Studies have shown that significant quantities of contaminants may be left behind in abandoned pipelines as a result of poor pigging and chemical cleaning practices (Det Norske Veritas, 2010). These remaining residuals could cause future issues primarily by directly contaminating the soil when the integrity of the abandoned line is compromised or by creating an environment within the abandoned pipeline that is conducive to internal corrosion (e.g., UDC and/or MIC).

At present, the main question of "How clean is clean?" is still remaining. The potential quantities and properties of the remaining contaminants within an abandoned pipeline are not fully known. The overall effectiveness of operators' cleaning procedures is also unclear. Subsequently, it is important for pipeline operators and other stakeholders alike to attempt to better understand the abandonment cleaning process as well as to potentially optimize the available cleaning techniques. Understanding these parameters will allow pipeline operators to better manage abandonment sites and reduce the potential release of these contaminants into soil and groundwater systems if the integrity of the abandoned pipeline becomes compromised.

In (Godin, 2014), the author discussed the issue of pipeline abandonment, among other issues, and recommended that more research is needed into 1) recommended practices for pipe abandonment including establishing levels of cleanliness and prevention of collapse; 2) the environmental and economic effects of pipe removal. This study aims at investigating cleaning methods, residual contaminants and current practices for pipeline abandonment, which will hopefully address the question imposed earlier (i.e., "How clean is clean?").

The main objectives of this research work are:

1. Review pipeline cleaning methods and current technologies for both chemical and mechanical methods;

2. Review pipeline products and identify the list of potential contaminants associated with each commodity;
3. Gather all relevant regulatory information available in Canada (federal and provincial) that address the subject of pipeline abandonment. Standards related to this subject are also reviewed (e.g. NACE International and CSA);
4. Investigate current abandonment programs and practices currently adapted in the industry by pipeline operators; and
5. Determine the appropriate tests to investigate the degree of contaminants that are actually present upon completion of the pipeline abandonment process and provide a market review of currently available field tests.

Gathering this information is essential in identifying gaps in the industry's pool of knowledge on the subject of pipeline abandonment in general and will serve as a starting point towards building a recommended practice for cleaning programs specific to pipeline abandonment.

The report is structured as follows: a literature review on pipeline cleaning, pipeline products and residual contaminants is given in Section 2, Section 3, and Section 4, respectively. The main regulations concerning pipeline abandonment are included in Section 5. Notes gathered from stakeholder engagement are detailed in Section 6. Current abandonment and cleaning programs are discussed in Section 7, followed by an overview for detection and testing techniques for residual contaminants in Section 8. Summary and conclusions are given in Section 9. Finally, recommendations for future work are outlined in Section 10.

2 PIPELINE CLEANING

For an active pipeline, cleaning is an essential and critical process to ensure safe operation and pipeline integrity. Cleanliness will ensure flow efficiency and the effectiveness of chemical inhibition programs. Similarly, it is critical to ensure that the pipeline is clean from all deposits and potential contaminants to prevent any future leakage and contamination to the soil for an abandoned pipeline. Over time, deposits may buildup in pipelines depending on the commodity being transported, the material of the pipeline and the operating conditions and configuration of the pipeline (process parameters, pipeline geometries, etc.).

The issue of pipeline cleanliness was discussed extensively in (Canada. Canadian Association of Petroleum Products, Canadian Energy Pipeline Association, Alberta Energy and Utilities Board, & National Energy Board, 1996). The paper states that if a pipeline is to be abandoned in place, no solids or waxy build up should be left or present in any place along the pipe and the contents should be cleaned to the extent that no more than a thin oily film on the inside pipe wall can be detected. In addition, levels of hydrogen sulfide (H_2S) need to be checked in sour liquid and natural gas pipelines in order to confirm that their levels are below acceptable limits. The authors in the aforementioned article suggested some cleaning guidelines and considerations for liquid and gas pipelines (reproduced here in Appendix A). In general, the owner/operator should ensure that the pipe is cleaned to a level where any remaining contaminants will not cause any potential harm in any intended use of the land. In the following subsections, we will review the common cleaning technologies used in the oil and gas (O&G) industry.

2.1 Mechanical Cleaning (Pigging)

Pigging is the process of removing debris from within a pipeline system by forcing a pig through the pipeline. The pig is oversized with respect to the internal diameter of the pipeline in order to ensure intimate contact with the pipeline wall and to prevent fluid by-pass. Typically, the pigging process consists of a launcher, a receiver, and the pig itself. A schematic of the pigging process is shown in Figure 1.

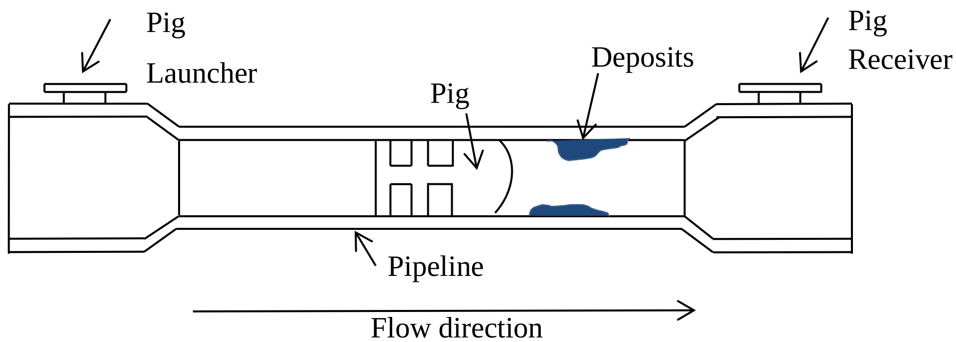

Figure 1: Representative schematic showing the pipeline pigging process.

Pigs can be either pushed with the flow through the pipeline (the flow is not interrupted in this case), or mechanically pulled (for pre-commissioning testing).

Pigs are used to serve different functions, such as filming pigs, cleaning pigs, smart pigs, batching pigs, gauging pigs, or displacement pigs, among others. Table 1 summarizes the different functions of a pig. The definitions in the table were gathered from (Pigging Products & Services Association (PPSA), 1995).

Table 1: Common Functions of Pipeline Pigs (Pigging Products & Services Association (PPSA), 1995)

Pig Function	Description
Batching pig	A utility pig that forms a moving seal in a pipeline to separate liquid from gas media, or to separate two different products being transported in the pipeline. The most-common configurations of batching pigs are cup pigs and sphere pigs.
Filming Pig	Applies any type of coating or film on the interior of a pipeline. The pig is designed with a bypass disc.
Displacement Pig	Used for filling and dewatering during hydrostatic testing, routine batching operations, product removal, and any operations that requires bidirectional use.
Camera Pig	A configuration pig that carries a video or film camera and light sources for photographing the inside surface of a pipe on an intermittent or continuous basis.
Cleaning Pig	A utility pig that uses cups, scrapers, or brushes, to remove dirt, rust, mill scale, or other foreign matter from the pipeline. Cleaning pigs are run to increase the operating efficiency of a pipeline or to facilitate inspection of the pipeline.
Configuration Pig	An instrumented pig that collects data relating to the inner contour of a pipe wall or of the pipeline. Geometry pigs, camera pigs, and mapping pigs are types of configuration pigs.
Gauging Pig	A utility pig that is permanently deformable by obstructions in the pipeline and thus, upon retrieval from the line, provides evidence of the worst-case obstruction in a given pipeline segment.
Gel Pig	A utility pig that is composed of a highly-viscous gelled liquid. These pigs are often used for pipeline cleaning and are sometimes called gelly pigs.
Geometry Pig	A configuration pig designed to record conditions, such as dents, wrinkles, ovality, bend radius and angle, and occasionally indications of significant internal corrosion, by making measurements of the inside surface of the pipe.
Intelligent/Smart Pig	A non-destructive testing technique to inspect the wall of a pipe. An in-line inspection tool is one type of instrumented tool.
Utility Pig	Pig that performs relatively-simple mechanical functions, such as cleaning the pipeline.

The most basic features of a cleaning pig are cups, discs, and brushes. However, cleaning pigs vary in design and it should be noted that the pig design will affect the effectiveness of cleaning. Pigs are made from different materials; for instance, foam pigs are made from polyurethane foam, while Mandrel (steel shaft) pigs have a metal body (steel or aluminum) with cups and/or discs made from polyurethane. Some of the common types of cleaning pigs are shown in Figure 2. The pigs shown here were solely selected for the purpose of displaying the variety of pigs that exist in the market and not for any other purposes.

The frequency of the pigging process will vary from one operator to another based on the diameter and length of the pipeline, the transported commodity and operational experiences. In general, pigging during the final operating stages is critical in preparing the pipeline for abandonment. It is important to note that, to the best of our knowledge, there is no publically available literature on the effectiveness of cleaning pigs in terms of their designs. Such information will be crucial for an operator and end user when selecting appropriate cleaning pigs and designing maintenance plans for their pipeline systems. Recent efforts at AITF have been targeting this issue. In (Mosher, Lam, & Tsaprailis, 2015), the authors systematically study the effects of pig design, oversize, and number of passages on the effectiveness of pig cleaning in oil and water systems.

(a) (b) (c) (d)

Figure 2: Photographs showing various mechanical cleaning pigs. (a) Foam pigs with different sizes and shapes. Some are equipped with brushes (Pipetech Corporation Ltd.); (b) Mandrel pigs with different combinations of disks and/or cups (Girard Industries); (c) Special design pigs (T.D. Williamson); (d) Pig with pencil brushes (Pipetech Corporation Ltd.).

2.2 Chemical Cleaning

Chemical cleaning denotes the use of liquid cleaners mixed with a diluent to form a cleaning solution that can be pushed through the pipeline. Cleaning with chemicals becomes necessary when debris and scales are adhering to the pipeline walls to the point that pigging alone cannot break the deposits. Therefore, chemical cleaning becomes essential in breaking up and softening of the scales inside the pipe and in removing hydrocarbon (e.g., wax) deposits.

Typically, chemical cleaning is done in conjunction with pigging. Cleaning is executed by pushing through the pipeline a batch of hydrochloric acid and water for rust removal, a neutralizer, and a passivator, all separated by batching pigs (McAllister, 2014). A batch of detergent can be added if the pipeline is being converted from crude oil to some other commodity to remove any traces of the crude oil. Chemical cleaning needs some extra care and time, while utilizing special equipment for handling the cleaning chemicals and properly disposing the spent material. Pigs also need to be selected carefully so they are not damaged by the cleaning chemicals (i.e., chemically compatible). The major advantage of chemical cleaning is the ability to remove a higher volume of debris with a smaller number of pig runs. In the absence of chemical cleaning, scales can become compact within the pipe preventing the movement of further cleaning pigs. These deposits can be broken up and softened by the addition of chemical surfactants (Cordell & Vanzant, 2003). Table 2 summarizes the key characteristics of chemical surfactants (Wylde J. J., 2011; Wylde & Slayer, 2009).

Table 2: Summary of Key Characteristics of Chemical Surfactants (Wylde J. J., 2011; Wylde & Slayer, 2009)

Characteristic	**Description**
Wetting	• the action of a surfactant to reduce surface tension of a media
Emulsification	• surfactants enable the formation of a stable emulsion of two or more immiscible liquids
Solubilizers	• surfactants that can affect otherwise insoluble materials
Dispersion	• surfactants that retain insoluble particles in suspension by preventing aggregation of particles with one another
Detergency	• the ability of a surfactant to remove particles from a surface

Diluted solutions of acids and alkalis have been used to perform chemical cleaning. Solutions of soda ash, caustic soda, phosphates, or silicates, plus synthetic detergents for better wetting and emulsifying, will remove oil, grease, and general soil (Savkovic-Stevanovic, 2013).

3 PIPELINE PRODUCTS

Pipelines are used for transporting large quantities of product over land efficiently and safely (CEPA - Types of Pipelines). Canada has a vast underground pipeline network consisting of gathering lines, feeder lines, transmission pipelines, and distribution pipelines. Maps of the natural gas pipelines and liquid pipelines (CEPA - Maps: Natural Gas Pipelines, Liquids Pipelines) have been reproduced in Appendix B of this report. Table 3 summarizes the products transported in the various lines (CEPA - Types of Pipelines).

For the purposes of this project, the focus will be on transmission pipelines while gathering, feeder and distribution pipelines are considered out of scope.

3.1 Crude Oil Pipelines

Each pipeline operator has quality specifications that a product must meet to be accepted for transportation. As an example, petroleum having the following general specifications will not be accepted (Enbridge Pipelines Inc., 2014) and (Kinder Morgan, 2014) (exact specifications may differ from one operator to another)

1. A temperature greater than 38 degrees Celsius;
2. A Reid vapor pressure in excess of 103 kilopascals;
3. Sediment and water in excess of 0.5 percent by volume;
4. A density in excess of 940 kilograms per cubic meter at 15 degrees Celsius;
5. A kinematic viscosity in excess of 350 square millimetres per second determined at the Carrier’s reference line temperature;
6. Any organic chlorides; or
7. Physical or chemical characteristics that may render such crude petroleum not readily transportable by the carrier or that may materially affect the quality of other commodities transported by the carrier or that may otherwise cause disadvantage to the carrier.

The types of crude oil produced in Canada and transported by pipeline, their properties and the crude streams can be seen in Table 4 (Crude Monitor 5 Year Average Data).

Table 3: Canada's Underground Pipeline Network[1]

	Gathering Lines	Feeder Lines	Transmission Pipelines	Distribution Pipelines
Types of Pipelines	These lines travel short distances gathering products from wells and move them to oil batteries or natural gas processing facilities.	Feeder lines move products form batteries, processing facilities and storage tanks in the field to the long-distance haulers of the pipeline industry, the transmission pipelines.	Transmission lines are the energy-highways, transporting oil and natural gas within a province and across provincial or international boundaries.	Local distribution companies (LDCs) operate natural gas distribution lines.
Products	Natural gas, crude oil and combinations of these products sometimes mixed with water; and natural gas liquids (NGLs) such as ethane, butane and propane.	Crude oil, natural gas and NGLs.	Natural gas transmission lines typically carry only natural gas and NGLs. Crude oil transmission lines carry different types of liquids crude oil and refined petroleum products in batches. Petroleum products lines also move liquids such as refined petroleum products and NGLs.	Natural gas is moved along distribution pipelines to homes, businesses and some industries.
Diameter	From 101.6 mm to 304.8 mm outside diameter (4 in. to 12 in.)		Range in size from 101.6 mm to 1,212 mm (4 in. to 48 in.) About half are 457.2 mm (18 in.) or larger, and about one third are 254 mm (10 in.) or smaller.	Most range in size from 12.7 mm to 152.4 mm outside diameter (half an inch to 6 in.)
Length	More than 250,000 kilometers of these lines are concentrated in the producing provinces of Western Canada, primarily in Alberta.	There are more than 25,000 kilometres of feeder pipelines in the producing areas of Western Canada.	There are approximately 115,000 kilometers of transmission lines in Canada.	There are about 450,000 kilometres of these lines in Canada.

[1] Reproduced from (CEPA - Types of Pipelines)

Table 4: Summary of Canadian Crude Streams (Crude Monitor 5 Year Average Data)

Type of Oil	Density (kg/m3)	Gravity (°API):	Sulfur (wt%)	Sediment (ppmw)	TAN (mgKOH/g)	Salt (ptb)	Nickel (mg/L)	Vanadium (mg/L)	Benzene (vol%)	Toluene (vol%)	Ethyl Benzene (vol%)	Xylenes (vol%)	Crude Streams
Condensate	673.5 - 758.2	55 - 78.4	0.03 - 0.24	15 - 248	-	-	-	-	0.69 - 0.92	1.02 - 2.49	0.09 - 0.29	0.47 - 2.35	Condensate Blend (CRW), Fort Saskatchewan Condensate (CFT), Peace Condensate (CPR), Pembina Condensate (CPM), Rangeland
Light Sour	823.5 - 849.2	35.0 - 40.2	0.62 - 1.52	-	-	-	ND - 17.5	1.6 - 42	0.18 - 0.51	0.65 - 1.12	0.24 - 0.49	0.97 - 1.46	BC Light (BCL), Boundary Lake (BDY), Gibson Light Sour (GLS), Koch Alberta (CAL), Moose Jaw Tops (MJT), Pembina Light Sour
Light Sweet	827.3-827.8	39.3 - 39.4	0.42 - 0.43	-	-	-	4.4 - 6.4	8.6 - 10.8	0.24 - 0.26	0.55 - 0.79	0.24 - 0.27	0.83 - 1.04	Mixed Sweet Blend (MSW), Rainbow (RA)
Pooled Crudes - ex Superior	835.4 - 932.5	20.1 - 37.7	0.12 - 3.66	165 - 378	0.16 - 1.52	9.9 - 61.6	ND - 52.2	0.8 - 131.2	0.06 - 0.41	0.19 - 0.76	0.08 - 0.45	0.25 - 0.75	Conventional Heavy (CHV), Hardisty Synthetic Crude (HSC), Light Sour Blend (LSB), Medium Sour Blend (MSB), Premium Conventional Heavy (PCH), Premium Synthetic (PSY),
Sweet Synthetic	838.9 - 864.8	32.0 - 37.1	0.05 - 0.18	-	-	-	ND	ND	0.03 - 0.19	0.15 - 0.48	0.10 - 0.22	0.33 - 0.70	CNRL Light Sweet Synthetic (CNS), Husky Synthetic Blend (HSB), Long Lake Light Synthetic (PSC), Premium Albian Synthetic (PAS), Shell Synthetic Light (SSX),
Medium Sour	847.3 - 874.8	30.1 - 35.4	1.57 - 2.26	268 - 342	0.20 - 0.49	0.55 - 62.9	15.7 - 29.4	29.8 - 79.1	0.06 - 0.76	0.2 - 1.39	0.12 - 0.60	0.46 - 1.16	Hardisty Light (MBL), Medium Gibdon Sour (MGS), Midale (MSM),
Heavy Sour - Conventional	915.1 - 933.0	20.0 - 23.0	2.76 - 4.75	115 - 307	0.21 - 1.82	10.0 - 45.9	28.4 - 58.6	78.1 - 145.7	0.02 - 0.21	0.18 - 0.32	0.05 - 0.18	0.1 - 0.51	Bow River North (BRN), Bow River South (BRS), Fosterton (F), Lloyd Blend (LLB), Lloyd Kerrobert (LLK), Seal Heavy (SH), Smiley-Coleville (SC),
Heavy Sour - Unconventional	923.4 - 928.6	20.8 - 21.6	3.51 - 3.94	91 - 288	0.94 - 2.30	3.9 - 39.9	47.0 - 73.0	122.3 - 193.2	0.11 - 0.29	0.25 - 0.49	0.02 - 0.11	0.13 - 0.43	Access Western Blend (AWB), Borealis Heavy Blend (BHB), Christina Dilbit Blend (CDB), Cold Lake (CL), Kearl Lake
Heavy Sour - Synbit	931.7 - 936.3	19.5 - 20.3	3.06 - 3.08	70 - 105	1.40 - 1.49	3.1 - 4.9	52.3 - 56.2	142.1 - 144.7	0.06 - 0.08	0.19 - 0.22	0.09 - 0.10	0.31 - 0.37	Statoil Cheecham Synbit (SCS), Surmont Heavy
Heavy Low Resid	936.4	19.5	3.09	102	3.53	4.6	4.4	10.6	0.03	0.11	0.05	0.2	Suncor Synthetic H (OSH)
Heavy Sour - Dilsynbit	939.2	19	2.43	656	0.5	11.4	44.6	86.3	0.15	0.33	0.11	0.37	Albian Heavy Sunthetic

* TAN = Total Acid Number

3.2 *Natural Gas Pipelines*

Natural gas consists primarily of methane with smaller amounts of other hydrocarbons; principally ethane, propane, butane, and pentanes (Canadian Gas Association, 2015). In addition, raw natural gas contains water vapor, H_2S, carbon dioxide, helium, nitrogen, and other compounds (NaturalGas.org, 2013).

Natural gas processing separates out all of the various hydrocarbons, water, impurities and other gases from the pure natural gas, to produce pipeline quality dry natural gas. While the processed natural gas is considered 'dry' gas, it is not uncommon for a certain amount of water and hydrocarbons to condense out of the gas stream while in transit. Each pipeline operator has quality specifications that the natural gas must meet to be accepted for transportation. A selection of quality specifications gathered from a number of operators is shown in Table 5.

Table 5: Natural Gas Quality Specifications (Trans Canada, 2014)

Specification	**Range of Maximum Values Allowed**
Hydrogen Sulphide (mg/m^3)	5.70 - 23
Total Sulphur (mg/m^3)	17 - 230
Carbon Dioxide (vol %)	2
Oxygen (vol %)	0.2 - 1
Nitrogen (vol %)	not specified - 3
Water (mg/m3)	64 - 112
Hydrocarbon Dewpoint (°C)	-10 to -7 (dependant on specified pressure)

4 RESIDUAL CONTAMINANTS

Residual contaminants that may remain in an abandoned pipeline could accelerate the corrosion and failure of the pipe, which in turn may lead to the release of contaminants to the environments. Potential sources of pipe contamination were listed in (Canada. Canadian Association of Petroleum Products, Canadian Energy Pipeline Association, Alberta Energy and Utilities Board, & National Energy Board, 1996). For example, deposited substances on the walls of a pipeline, deposited treatment chemicals, degraded coatings, leaks and spills, and PCB contamination, were all considered sources of possible contaminants. The discussion paper concluded that the effectiveness of pigging and cleaning, prior to the abandonment, is a key factor in determining the level of residual contaminant in the pipe. Table 6 summarizes potential contaminants in a pipeline based on the media that it is transported as was discussed by the authors in (Wylde & Slayer, 2009).

Table 6: Potential Contaminant in a Pipeline Based on the Commodity Transported (Wylde & Slayer, 2009)

Media	Contaminant
Crude Oil	- Organic scale deposits (Paraffins, asphaltenes, and naphthenates).
Gas	- Organic scale deposits; - Mercury based scales; - Arsenic based scales; - Zinc based scales; and - Lead based scales.
Water	- Corrosion deposits (iron carbonate, iron oxides, hydroxides, oxyhydroxides, and iron sulfide).

A more detailed discussion on contaminants in crude oil and gas pipelines, respectively, is given in the next subsections followed by a review of possible contaminants from cleaning chemicals.

4.1 Crude Oil Contaminants

Crude oil is not corrosive to steel pipelines under normal operating conditions; an electrolyte such as water is required for corrosion to occur. In the case of pipelines, sludge deposits can form and are composed of varying combinations of hydrocarbons, sand, clay, corrosion by-products, microorganisms and water. These sludge deposits are known to accumulate and concentrate water from the oil at the pipeline surface shifting the oil-wet surface to a more corrosive water-wet environment that could also promote localized UDC. In recent years, significant work has been conducted on improving the general understanding related to the circumstances that may lead to internal corrosive conditions (Been, et al., 2011; Crozier, Been, Tsaprailis, & Place, 2013). Recent studies conducted at AITF have identified MIC as a key factor in the phenomenon of crude oil UDC (Mosher , et al., 2014; Mosher, et al., 2012). It has also been determined that the formation of sludge on a metal surface alone is not enough to facilitate significant corrosion.

MIC is a very specialized area of corrosion and can be induced by the presence of any number of microbial species. In the case of crude oil pipelines and sludge deposits, the presence of SRB, APB and HAB has been confirmed through culturing techniques from the bulk sludge samples (Garcia, Place, Holm, Sargent, & Oliver, 2014). MIC has been estimated to account for 30 – 40 % of all internal corrosion-related failures (Sooknah, Papavinasam, & Revie, 2007). Understanding the microbial communities and sludge properties associated with UDC will aid in the development of robust mitigation strategies for corrosion prevention (Garcia, Place, Holm, Sargent, & Oliver, 2014).

The composition of sludge deposits can change from one pipeline to another and even within the same pipeline. Typical sludge deposit analysis methods include the Dean-Stark analysis, compositional analysis using energy dispersive EDS/EDX, and XRD. Dean-Stark analysis is used to determine the water to solid percentage in the sludge, while EDX and XRD are utilized for the elemental analysis or chemical characterization of a sample. In (Crozier, Been, Tsaprailis, & Place, 2013), the authors analyzed five different sludge deposits obtained from a crude oil transmission pipeline. The results of the Dean-Stark and XRD preformed are reproduced in Table 7 and Table 8.

Table 7: Dean Stark analysis for the sludges (Sludge samples A, B, and C (Crozier, Been, Tsaprailis, & Place, 2013). Sludges D and E are obtained from personal correspondence and permission from the operator)

	Sludge A	**Sludge B**	**Sludge C**	**Sludge D**	**Sludge E**
Solid (wt%)	47.0	72.3	85.0	83.55	90.30
Oil (wt%)	18.8	22.7	4.5	11.53	6.4
Water (wt%)	19.5	2.9	10.4	3.16	2.38
Total Recovery (wt%)	85.3	97.9	99.9	98.24	99.09

Table 8: Composition of sludge solids as determined by X-Ray diffraction (Sludge samples A, B, and C (Crozier, Been, Tsaprailis, & Place, 2013). Sludges D and E are obtained from personal correspondence and permission from the operator)

Name	**Formula**	**Sludge A**	**Sludge B**	**Sludge C**	**Sludge D**	**Sludge E**
Quartz	SiO_2	82.3	95.0	85.0	2.1	0.9
Microcline	$KAlSi_3O_8$	4.2	-	-	-	-
Albite	$NaAlSi_3O_8$	2.7	-	-	-	-
Greigite	Fe_3S_4	5.6	-	-	8.6	5.2
Pyrite	FeS_2	2.5	-	-	4.2	2.9
Magnetite	Fe_3O_4	1.8	-	-	20.9	14.8
Halite	NaCl	0.9	-	-	-	-
Plagioclase	$(Na,Ca)(Si,Al)_4O_8$	-	5.0	5.0	-	-
Goethite	FeO(OH)	-	-	5.0	18.4	11.2
Magnesioferrite	$Mg(Fe^{3+})_2O_4$	-	-	5.0	-	-

Table 7 shows that the predominant constituents of the sludge deposits are solids (47.0 – 90.3 %), while the water component ranges from 4.5 – 19.5 %. Dean-stark extracted solids were compositionally analyzed using XRD and the majority of the composition were found to consist of SiO_2 (i.e., sand) for Sludge A – C, while sludge deposits D and E contain more Fe compounds.

Only crystalline compounds are XRD active. Consequently, the authors in (Been, et al., 2011) also presented the results from the analysis conducted on four different crude oil transmission sludge deposit samples. The Dean-Stark analysis lead to similar results for the oil, water and solid percentage as reported in (Crozier, Been, Tsaprailis, & Place, 2013). They also preformed EDX analysis on the sludge samples. They found that O was the most present element (37.1-54.9 %) followed by Si (14.4 - 31.3%) and then Fe (3.4 - 27.34 %). Other elements such as C and S also existed in the four sludge deposits but to a lesser percentage. Full results of the EDX analysis are reproduced in Table 9.

Table 9: EDX Analysis (%wt.) for Different Transmission Pipeline Sludge Samples (Been, et al., 2011)

	C	O	Si	S	Fe
Sludge I	6.1	54.9	31.3	0.6	3.4
Sludge II	5	49.2	30	1.6	10.8
Sludge III	11.6	37.1	14.4	6	27.34
Sludge IV	6.6	46.2	26.9	1.0	14.6

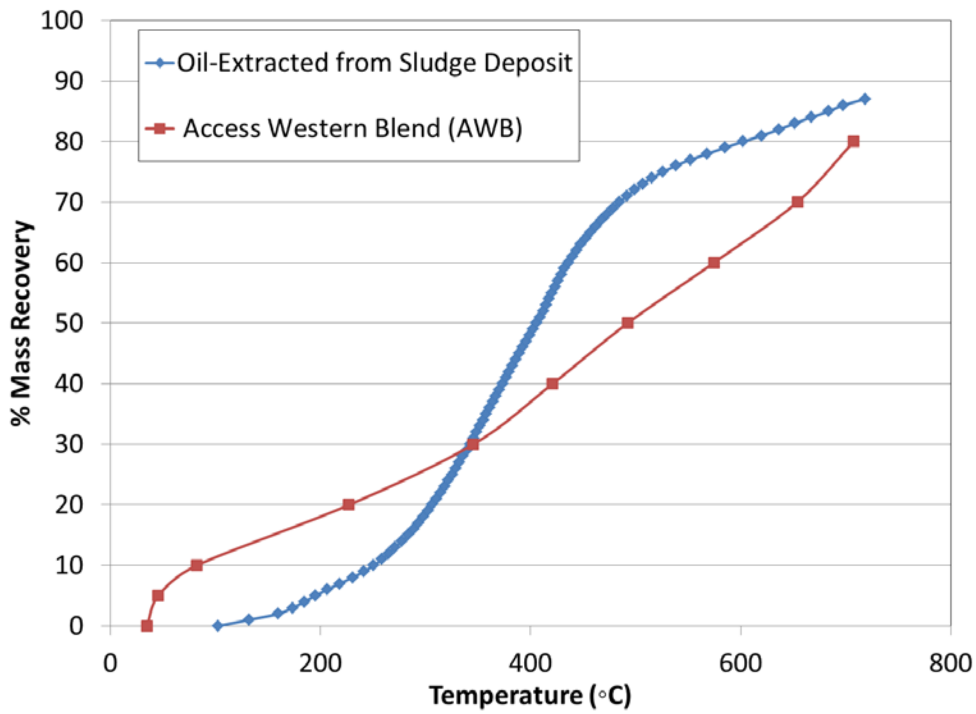

Figure 3: High temperature simulated distillation using ASTM D7169 for an Athabasca crude oil (AWB, ■) and oil-extracted from an Athabasca crude oil sludge deposit (♦)[2].

It should be noted that the hydrocarbon content within the sludge deposits are not directly representative of the transported commodities. Microbes within the sludge deposits have the ability to process the hydrocarbon content as nutrients, thereby, changing the composition of the hydrocarbon content within the deposits. Figure 3 shows the high temperature simulated

[2] Figure provided by AITF and is based on internal research completed on sludge deposits from crude oil transmissions and is referenced herein with permission from AITF.

distillation (HTSD) curves for an Athabasca crude oil (Access Western Blend, AWB) and oil-extracted from an Athabasca sludge deposit. The HTSD were obtained according to the ASTM International standard D7169 (ASTM International, 2011) and shows the % mass recovery at various temperatures. As seen in Figure 3, no significant mass recovery is obtained from the oil-extracted from the sludge deposit at temperatures below 100 °C, while 10.15 % mass recovery is seen from the AWB crude oil. The HTSD data suggests that there are relatively no light hydrocarbon fractions (e.g., alkanes with a carbon number below seven, C7-) within the sludge deposit. Interestingly, the oil-extracted from the sludge deposit showed a higher composition of medium oil fractions (C17+) that have boiling points in the range of ~ 300 – 500 °C.

4.2 Natural Gas Contaminants

Transmission gas pipelines provide energy within province and across international boundaries. Natural gas and natural gas liquids are the main commodities transported through gas pipelines. The quality of natural gas varies when it is produced even when it meets specifications; consequently, the residual contaminants found are expected to vary as well depending on the quality of gas transported. Residual contaminants such as black powder, hydrocarbons, PCBs, and NORMs as well as other trace contaminants have been observed even after pipeline cleaning has been performed (Thorne, Basso, & Dhol, 1996). Consultation with industry experts as well as literature have been used to prepare a summary of substances that may be released by abandoned oil and gas pipelines (Thorne, Basso, & Dhol, 1996) and has been reproduced in Appendix C of this report. A more detailed discussion on natural gas contaminants is given next.

- *Black Powder:*

Black powder is a common contaminant that has been found in gas pipelines lines across the world. It is comprised of number of corrosion related contaminants but its composition has been found to be dependent on the gas that is transported. Black powder is a very hazardous chemical compound that “is not well understood in terms of composition and physical properties, source, formation, prevention, or management of its effects” (Sherik, 2008). The main hazard is the material’s flammability especially when the material is dry and fine. When black powder is made up of primarily pyrrhotite ($Fe_{(1-x)}S$; x = 0 to 0.2), it exhibits pyrophoric properties and has been reported to auto-ignite. (Trifilieff & Wines, 2009).

As black powder can be found in varying amounts depending on the quality of product being transported, it has the potential to have harmful effects on equipment as well as impede flow and efficiency if found in sufficiently large quantities. Black powder has been observed to have had the following effects on gas pipelines: reduced flow efficiencies, clogged and collapsed filters, deposited on gas measurement devices, clogged instrumentation and valves, accelerated deterioration of valves due to erosion, and created maintenance and safety concerns (Tsochatzidis & Maroulis, 2007). Literature has shown that black powder consists of iron oxides, iron sulfides and iron carbonates in varying forms and in varying amounts. Internal MIC of pipeline walls is believed to be the source of this residue even though it has been found present in both newly commissioned and pre-existing pipelines. Some potential sources of black powder are listed in Table 10 (Sherik, 2008).

Table 10: Potential Sources of Black Powder Contents (Sherik, 2008)

Compound	**Potential Sources**
Fe_3O_4	- Low dissolved oxygen-induced corrosion - Conversion of γ-FeOOH - Bacterial-induced corrosion (APB, IOB) - Conversion of $FeCO_3$ and FeS (in situ) due to oxygen ingress - Mill scale (minor and short-term)
FeOOH	- Low dissolved oxygen-induced corrosion
Iron sulfides	- H_2S-induced corrosion o Chemical source o Bacterial source (SRB)
Siderite – $FeCO_3$	- CO_2 corrosion

The information available on the formation and composition of black powder is limited leaving room for further research to expand on our understanding of its presence and potential effects on active and abandoned pipelines.

- *Hydrocarbons and NORMs:*

Raw natural gas consists of varying amounts of hydrocarbons that have to be processed to meet pipeline specifications for transportation. Upon analysis of internal pipeline wall deposits, the following residual hydrocarbons have been reported in literature: "BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), PAHs, waxes, gums, resins and hydrocarbon degradation products" (Thorne, Basso, & Dhol, 1996).

Corrosion by-products as well as radon and radon-decay products from natural gas production and processing facilities have also been reported from the analysis of scale deposits in gas pipelines (Thorne, Basso, & Dhol, 1996). Radon and radon-decay products are naturally occurring radioactive materials (NORMs).

The two main radioactive decay series of concern in the O&G industry are Uranium-238 and Thorium-288, of which the nuclides of concern are Radium-226 and Radium-228, respectively. Radon-222 is the immediate decay product of Radium-226. When produced with oil and gas, radon will usually follow the gas stream. Radon-222 decays (through several rapid steps) to Lead-210, which can, therefore, build up as a thin film in gas extraction equipment. The radioactive decay series of Uranium-238 and Thorium-288 have been reproduced in Appendix D of this report. The figures in the appendix show the radionuclides, their radioactive half-lives, decay mechanism and the manner in which they are mobilized (International Association of Oil and Gas Producers, 2008).

Radon-222 gas is found in most natural gas deposits in the world. When brought to the surface, it will enter the gas production stream (Canadian Association of Petroleum Producers, 2000). Radon-222 has a relatively short half-life (3.8 days) and is not easily absorbed by the body. The longer lived decay products, such as lead-210, bismuth-210 and polonium-210, cause contamination that can be a health hazard. Lead-210 is of particular concern as the half-life is 22 years. As radon decays, thin radioactive lead films may form on the inner surfaces of gas processing equipment and transportation lines. Radon decay products can contaminate sludge within the pipeline, which in turn may contaminate the pig used to clean the pipeline (Gray, 1991).

NORMs in the O&G industry pose a health hazard particularly during maintenance, waste transport and processing, and decommissioning. Radioactive lead, bismuth and polonium may be inhaled or ingested when attached to scale or dust generated during the pipeline abandonment process. Exposure to radon decay products has been linked to an increase in lung cancer (Canadian Association of Petroleum Producers, 2000). The presence of radon decay products cannot be detected on the outside of the pipeline as they are easily absorbed by the pipeline walls. An alpha/beta probe held close to the contaminated surface may detect their presence but with low efficiency. Any reading above background would be an indication of significant contamination. Laboratory analyses of samples taken from the internal surface would be required to determine the concentrations of lead, polonium and bismuth (Gray, 1991).

- *PCBs:*

In the past, hydraulic/lubricant oils used in both gas turbines and air compressors contained PCBs. These oils were used for their insulating capabilities, fire retardant and lubricating properties but emit PCBs in the process allowing for a source of contamination. The service air from the air compressors was often used for the natural gas compressors allowing for PCB contamination to spread. Even with effective pigging, PCBs and NORMs have been identified as remaining in a limited number of gas transmission lines (Thorne, Basso, & Dhol, 1996). PCB manufacturing was banned in 1977 in North America and the release of PCBs into the environment was made illegal in 1985. They are very toxic due to their stability and do not break down readily in the environment. The use of lubricant oils containing PCBs in these compressor stations allowed for PCBs to be absorbed onto paint on walls, floors, pipes, engines, and soils (Semmens, 2013). Some of the common Aroclors found in PCB containing lubricant oils used at compressor stations are Aroclor 1221, 1232, 1242, 1248, 1254, 1260, and 1268. The contamination of natural gas pipelines could have resulted from lubricating oils that leaked past compressor seals and traveled through the pipeline with formed liquid condensate. During the 1940s – 1960s oil fogging was a commonly used gas conditioning technique where PCB containing oil vapor fogged the pipeline system. This procedure is no longer in practice but residues may still remain in parts of natural gas pipelines.

4.3 Cleaning Chemicals Contaminants

Pipeline pigging techniques are used in the cleaning of both liquid and natural gas pipelines. As mentioned in Section 2.2, chemical cleaning assists the pigging process by the addition of surfactant based chemicals using batching pigs. However, the use of these chemicals during cleaning operations could potentially result in residual contaminants on the pipeline wall. There is limited information available on commercially available chemicals used for chemically assisted pigging, thus it is difficult to identify all of the potential residual contaminants. In

Appendix C of this report, some of the treatment chemicals used in cleaning pipelines is tabulated. These treatment chemicals are potential sources of residual contamination and should be taken into account as their presence is dependent on the effectiveness of pigging. For example, hydrochloric acid is used for the removal and control of calcium carbonate-type scale (Thorne, Basso, & Dhol, 1996) and, if not completely neutralized or removed, could increase the rate of the pipeline wall corrosion. The order of cleaning chemicals used during pigging is also of concern. If the last chemical in the cleaning sequence is hazardous, it could have the potential to leave hazardous residue and/or make the existing residue hazardous.

5 REGULATIONS

In this section, the main Canadian regulations (both federal and provincial) and standards related to pipeline abandonment were reviewed. For the purposes of this report, the focus will be mainly on the regulations and laws that concern the cleaning of a pipeline and/or the level of contaminant prior to abandonment. Therefore, this section is not intended as a comprehensive summary of the regulations that govern the process of pipeline abandonment in its entirety. Provincial regulations are first presented starting with Alberta and followed by other Canadian provinces. Federal regulations are presented thereafter.

Pipelines within Alberta that do not cross provincial or national boundaries are regulated by the AER and must adhere to the Alberta Pipeline Act (Canada. Province of Alberta, 2014). The act states the responsibilities of a licensee before abandoning a pipeline or a section of a pipeline in part 10, section 82: "*Discontinuance or abandonment of pipeline*". In addition to all the other requirements, the licensee shall ensure that the pipeline is:

a- *"Cleaned, if necessary;"*
b- *"Purged with fresh water, air or inert gas, any of which may include the addition of internal corrosion inhibitors if the licensee is prepared to mitigate the environmental effects that could occur as a result of accidental release or spillage;"*
c- *"Protected by suitable internal and external corrosion control measures; and"*
d- *"The contained fluids are confirmed and documented as being non-corrosive."*

The Alberta Pipeline Act requires the licensee to identify all ends with a permanent tag that indicates, among other things, the abandonment media left inside the pipeline. In addition, the act states that the licensee shall comply with all the requirements in Directive 056: "*Energy Development Applications and Schedules*" (Canada. Alberta Energy Regulator, Sept. 1, 2011). The directive defines pipeline abandonment as the permanent deactivation of a pipeline in a manner prescribed by the pipeline regulation. The directive specifies the duties of a licensee when abandoning a pipeline, as follows:

a- "To conduct notification with parties and those affected by setbacks along the entire pipeline right-of-way prior to any abandonment procedures (following table 62 in the directive);"

b- "To ensure that proper abandonment procedures are in place following section 82 in the pipeline regulation (Alberta Pipeline Act); and"

c- "To submit a license amendment application notifying Facilities Applications of the abandonment within 90 days of the pipeline abandonment."

Next, the CSA Standard Z662 for Oil and Gas pipeline Systems, (Canadian Standard Association (CSA), 2015), Clause 10.16: "*Abandonment of Piping*", states- among other requirements- that piping that is abandoned in place shall be:

a- "*Emptied of service fluids*;"

b- "*Purged or appropriately cleaned or both in a manner that leaves no mobile materials remaining in the pipeline*;"

c- "Physically separated from any in-service piping;"

d- "Capped, plugged, or otherwise effectively sealed;"

e- "Cut off at pipeline depth; and"

f- "Left unpressurized."

In the next paragraphs, an overview of the regulations in some Canadian provinces is given. The Pipeline Regulations in Saskatchewan (Canada. Province of Saskatchewan , 2014) has a section titled "*Abandonment of pipeline*" in which they state the following:

"A licence holder applying for a licence or an amendment to a licence to permit the abandonment of a pipeline shall include the following with the application:

a- The reasons for the abandonment;

b- The details of the abandonment procedure, which is to include:

- *i- The purging of the substance carried by the pipeline using fresh water, air, an inert gas or other cleaning substance;*
- *ii- The cutting of the pipeline at both ends at the buried depth and the welding of steel plates or caps over the openings; and*
- *iii- The removal of all above-ground facilities and the restoration of any land utilized by the pipeline."*

In Manitoba, the Drilling and Production Regulation (Canada. Province of Manitoba, 2001) comprises two clauses, 98 and 99, that address pipeline suspension and abandonment of a flow line, respectively. Clause 98, *"suspension of flow line"*, states that if a flow line has not been used for a period of 6 months, the licensee shall, unless approval by an inspector is obtained, suspend the flow line by:

- *a- "Filling the flow line with air, fresh water, or nitrogen;"*
- *b- "Isolating the flow line from all pressure sources; and"*
- *c- "Taking any additional measure required by an inspector to leave the flow line in a safe condition."*

Clause 99, "*abandonment of flow line"*, states that "*A licensee who abandons a flow line shall do so by cutting and capping both ends of the flow line at least 1.5 m below ground level and complying with clauses 98(a) and (c)."*

In British Columbia, the issue of pipeline abandonment/deactivation is addressed in more than one place. For instance in section 10 of the Pipeline Operations manual (British Columbia Oil and Gas Commission, 2015) there is a paragraph titled "*Amendment to Abandon*" that indicates the steps needed to be taken in order to abandon or deactivate a pipeline. The paragraph explains that:

"This amendment applies to pipelines which are being abandoned in the ground or which are being removed. Pipelines may be abandoned in place if they are properly de-activated in accordance with CSA Z662; are cut and capped below grade; and include identification markers."

On the responsibility of the pipeline licensee, the document states that:

"For lines being abandoned in the ground, the abandoned line must remain registered with BC One Call and above ground marker posts must be maintained. The company remains liable for the environmental impacts of the pipeline remaining in the ground. An updated as-built must be submitted showing the portions of the pipeline abandoned in place. For abandoned lines removed in their entirety, the description page must include the removal and the date of the removal. Registration with BC One Call is not required if the line is being removed, but the operator is responsible for restoring the land after the removal."

Finally, the document mentions that "*documentation supporting the rationale for abandoning in place or removing (as required by CSA Z662 clause 10.16.1) may be requested for this application."*

More regulations pertaining to pipeline abandoning/deactivation in British Columbia can be found in the Pipeline Regulation (Canada. Province of British Columbia, 2014) which is part of the Oil and Gas Activities Act. The regulations address the issues of pipeline deactivation and abandonment in section 9 and 11, respectively. Section 9, "*Deactivation*", states that

"If a pipeline permit holder has not transported fluids through the holder's permitted pipeline or part of a pipeline for 18 consecutive months, the pipeline permit holder must

- *a- Submit a plan for resuming the transportation of fluids through the pipeline, or*
- *b- Deactivate the pipeline or part of the pipeline in accordance with CSA Z662 and notify the commission on completion of the deactivation."*

And section 11, "*Obligations on cancellation or cessation of operations"*, states that

"The following requirements are prescribed with respect to a pipeline permit for the purposes of section 40 (e) of the Act:

- *a- Abandon the pipeline in accordance with CSA Z662;*
- *b- Do everything referred to in section 19 (1) (a) to (g) of the Environmental Protection and Management Regulation."*

It should be noted that Ontario and Quebec did not have specific regulations for the cleaning of abandoned pipelines.

Pipeline systems that cross provincial or national borders or the Canada/USA international borders are regulated by the NEB Act (Canada. National Energy Board, Act (R.S.C., 1985, c. N-7), 2014) and the NEB onshore pipeline regulations (Canada. National Energy Board, Onshore Pipeline Regulations (SOR/99-294), 2015). In this connection, section 74 of the NEB Act requires that a company shall not, without the leave of the NEB, abandon the operation of a pipeline. Additionally, section 45.1 of the NEB Onshore Pipeline Regulations requires that an application be filed for the proposed decommissioning of pipeline facilities. For both types of applications, the NEB requires that the applicants provide the reasons for the decommissioning or abandonment and the procedures to be used (NEB Onshore Pipeline Regulations, Sections 45.1 and 50). The required contents of an abandonment application are also addressed in Guide B of the NEB's Filing Manual. Among other things, this guide stipulates that applicants are to confirm that abandonment activities will follow the applicable requirements of the latest edition of the CSA Z662 standard. The guide also requires applicants to provide:

- *a- "an assessment of potential safety hazards related to the abandonment and mitigation actions planned to reduce such hazards;"*
- *b- "description and justification for the methods that will be used to identify and clean up any contamination found at the project sites including;*
  - *i. the amount of contamination that may exist;*
  - *ii. special handling techniques that will be used; and*
  - *iii. regulatory requirements that will be followed for cleanup and disposal;"*
- *c- "how the environment will be reclaimed; and"*

d- *"how the abandonment method is appropriate for the ecological setting where it is located;"*

6 STAKEHOLDER ENGAGEMENT

In this section, the engagement with stakeholders is presented. The main methodology employed in gathering information was one-on-one and/or telephone interviews with stakeholders. The stakeholders identified in this study were federal and provincial regulators (the NEB and the AER), pipeline operators (mainly oil and gas transmission companies), and pipeline cleaning suppliers (mechanical and chemical). In the next subsections, the outcomes of the interviews are summarized.

6.1 Regulators

The interviews with the NEB and the AER, respectively, are summarized below:

- *National Energy Board (NEB):*

  Glossary:

  - Pipeline deactivation: Pipeline may return to service.
  - Pipeline decommissioned: Pipeline will cease operation, but the service is still continuous through either a looped line or replacement pipe.
  - Pipeline abandoned: Pipeline will cease operation and the service is discontinued.
  - Pipeline discontinued: The NEB does not use this term for pipeline status. It only uses this term for service by the pipeline system.

  Summary Notes from NEB Interview:

  - The NEB is requiring each company to establish a post-abandonment fund to finance abandonment and post-abandonment if a pipeline is abandoned or the pipeline owner ceases to exist.
  - Prior to abandoning a pipeline, the NEB will call for a public hearing to get the landowners and other authorities input on all aspects of the abandonment including which portions to abandon in place or remove.

- The abandonment fund is not required by any other jurisdictions.
- There are no mandates on the level of residual contaminants left in a pipeline after abandonment. However, the NEB hearing will consider evidence on any environmental risks posed by the abandonment and the NEB has the power to issue directives on the process that can mandate certain things (e.g. cleaning methods).
- There are no mandates on specific cleaning methods to be used prior to abandonment (unless special directives are issued).
- The regulations do not differentiate between pipelines based on their commodity (crude, gas).
- Third party inspection or over-sight for the abandonment cleaning process is not required.

- *Alberta Energy Regulator (AER):*

  Glossary:

  - Pipeline discontinuation: pipeline is emptied, cleaned, purged, capped, and cathodic protection (CP) left on with the intent to preserve the line for potential reuse.
  - Pipeline abandonment: pipeline is emptied, cleaned, purged, and capped with the intent of not reusing it.

  Summary Notes from AER Interview:

  - AER regulates ~ 290,000 pipeline segments.
  - At the end of 2012, there was ~ 34,500 km of discontinued and 37,000 km of abandoned pipelines licensed in Alberta.
  - AER *Pipeline Regulations* requires pipeline owner to have perpetual liability for abandoned pipelines in Alberta.
  - The licensee is responsible for abandoned pipelines. If the assets are sold, the responsibility is transferred to new owner (The operator may not necessarily be the licensee – facilities can be operated on behalf of the owner by another company.).
  - The OWA has funds to abandon wells and pipelines that do not have a viable owner:
    - Operating companies pay levee into fund.
    - The OWA is a separate corporate entity from the AER.

  - There is a legal process for the OWA to follow to take responsibility for the pipeline.

- There are no specified inspection intervals although operators are required to conduct pipeline monitoring and inspection as necessary to maintain operational integrity. Once a pipeline is abandoned, there is no expectation that pipeline integrity is to be maintained. Although, operators will still perform scheduled right of way (ROW) inspections. ROW inspection will show if the pipeline has been exposed above ground over time.
- AER does not regularly inspect during the pipeline abandonment process. Although, AER can direct licensees to correct any deficiencies.
- The AER does not hold hearings prior to pipeline abandonments and there is no application for pipeline abandonment.
- The land owner is contacted by operator and can request removal but it is not required by legislation.
- Non-compliance is usually in terms of record keeping or paperwork. For example, the pipeline operator must inform AER about the status change in the pipeline within 90 days.
- Requirements for cleaning methods/standards of cleanliness in the regulations are goal-based:
  - Line must be cleaned and purged of fluids.
  - Licensees are to make their best reasonable effort.
  - Guiding principle is to not leave anything behind that could leak or cause contamination.
- Although the regulations are goal-based, there are no specifications on cleaning methods for abandoned pipelines or levels of residual contaminants left in a pipeline.
- Also, the regulations do not differentiate between pipelines based on their commodities.
- ~ 99 % of pipelines are abandoned in place. If it is in the way of future development, it will be removed:
  - Preferable to leave pipelines in place. Removal of the pipeline could result in soil admixing and/or vegetation cross contamination from machinery used to dig and remove the pipeline.

  - Removal of pipelines used in water systems raises the concerns of NORMs from the pipe scale.
  - Any salvage value is far exceeded by removal costs.
- There are no foreseeable changes in the regulations at least in the short term.
- Some older lines were not really set up to be pigged (e.g. small diameters, tight bends, diameter changes). In this case, rinsing with water is used.
- Pigging waste
  - If all the waste is oil, it can be sold.
  - Oilfield waste is regulated under Directive 58 'Oilfield Waste Management'.
- Aggressive cleaning sometimes may cause more problems because:
  - It might knock debris or scale loose that were otherwise firmly attached to the pipe.
  - The pig may become stuck in loose debris.
- There is no third-party inspection to the abandonment process and it is left to the due diligence of the operators. There are random checks from time to time.
- The licensee's responsibilities are to purge and clean the pipeline, isolate and cap it, notify landowners as required, amend the AER licence record, and change and keep the appropriate records of abandonment.
- Operators pay no property taxes on abandoned pipelines, only on operating (full tax rate) and discontinued ones (10% tax rate).
- Pipeline stoppers can be used if water transfer within the pipe is considered a concern. This is seldom done in gathering pipelines as average segment length is about 1.4 km.
- NEB does not typically engage AER in the NEB pipeline abandonment hearings. Once NEB removes the pipeline from its books, it is unclear who may have jurisdiction over former NEB pipelines. This is a grey zone as the NEB has removed the pipeline operator's responsibility.
- 92 % of all pipelines under the AER oversight are 8 inch diameter and smaller.

6.2 Pipeline Operators

Here, the findings from interviews with the pipeline operators are summarized. In the interview process, operators were asked two sets of questions; one set was focused on pipeline cleaning prior to abandonment, while the other set was more specific for the overall pipeline abandonment process. First, the notes related to the pipeline cleaning process are presented. It should be noted that the following answers were gathered from pipeline companies transporting mostly natural gas, namely Alliance Pipelines Incorporated (Alliance) and TransCanada Pipelines Limited (TCPL).

1. *Number of pig launchings:*
   - As much as necessary. In general, it would change from case to case and will depend on the amount of waste that you would receive at the pig traps.
   - Depends on the length of pipe, the product, diameter, and its location.

2. *Types of cleaning pigs used and their selection process:*
   - Polyurethane squeegee pigs.
   - Soft or no brushes for internally coated pipelines. Solid brushes for pipelines that are not internally coated.
   - Progressive pigging (i.e. using more than one type of pigs during the cleaning job.)

3. *Using chemical cleaning and/or corrosion inhibitors:*
   - Since the interviewed pipeline operators were mainly natural gas transportation companies, internal corrosion was not an issue and hence neither corrosion inhibitors nor chemical cleaning were used.
   - Corrosion inhibitors were only used on the crude oil pipelines.
   - In the future, chemical cleaning will be an integral part prior to pipe abandonment.

4. *Assessing the effectiveness of cleaning:*
   - In general it is case by case.
   - Will depend on the amount of waste/material removed after each pig run.

- ILI and smart ball are also used to assess the effectiveness of cleaning and integrity of the pipeline.

5. *Typical contaminants recovered after a pig run:*
   - Compressor oil, hydrocarbons, water, and metal from the pipe.
   - NORMs

6. *Sampling and testing the residues:*
   - No field tests, all samples are sent to the lab.
   - Typically lab tests will be for the composition and concentration of the recovered waste.
   - For in-service lines sampling will typically be needed if too much waste is coming out from the pipeline after pigging. No need to sample if the pipeline is clean and dry.
   - For abandonment purpose sampling is a critical issue and there might be a need for field tests. The pipeline will be segmented into sections and samples will be taken along the pipeline length to make the sampling process statistically viable.

7. *Shortcomings with current cleaning techniques:*
   - The outstanding issue is still answering the question of "How clean is clean?"

Next, the question set specific to the overall pipeline abandonment process is presented. It should be noted that out of the companies that AITF engaged, Enbridge Pipelines Incorporated (Enbridge) is currently preparing for the replacement (and decommissioning) of Line 3. As part of the NEB hearing, Enbridge has publicly provided their cleaning guideline for the pipeline abandonment process (discussed in more details in Section 7). Alliance and TCPL responded differently to this section of the questionnaire. For instance, Alliance[3] had a few pipeline segments that were deactivated and as such some of the questions in the interview were not relevant. On the other hand, TCPL[4] has upcoming pipeline abandonment projects (natural gas lines) that are proposed. Similar to Enbridge, TCPL will have a dedicated team that focuses on

[3] Communication with Alliance Pipeline Incorporated.
[4] Communication with TransCanada Pipeline Ltd.

their upcoming pipeline abandonment projects. Below, a summary of the engagement with the operators is presented:

1. *Abandoning in place versus removal of the pipeline :*
   - Most of the pipelines (~ 90 %) will be left in place (cost prohibitive to remove all pipelines).
   - Removing a pipeline from its place can cause more damage to the environment.
   - A pipeline will be removed if it is blocking the way for construction or future development plans for the land.

2. *Percentage of pipelines abandoned vs. discontinued:*
   - In general, it is case by case.
   - Some operators will just abandon, as there is no point of deactivating and the cost of bringing the pipeline back to service after deactivation is high and involves several steps.
   - Some operators will prefer to decommission a pipeline (by leaving the cathodic protection on) instead of abandoning it (even if there is no immediate intention to bring the pipe back to life).

3. *Abandonment-specific program within the company:*
   - Currently, there is not a special program for abandonment, but as the pipeline network is growing and aging, and with the current abandonment plans, there is a direction in some operating companies to create a task force dedicated to this issue and a special program/unit to deal with pipeline abandonment.

4. *Typical steps performed before and during the abandoning process:*
   - Environmental assessment.
   - Checking for creeks and crossings.
   - Sampling and checking for liquid left in the pipeline.
   - Cleaning, purging, and capping as instructed in the CSA Z662 standard.
   - Cleaning steps are the same whether the pipeline is left in place or removed.

5. *Post-abandonment inspection:*

- In general, it is case by case.
- Decommissioned pipelines are treated like in-service pipelines with inspection and aerial surveillance.
- No inspection or surveillance for abandoned pipelines.
- Typically, land owners will come forward with any issues that arise from the abandoned pipeline, if any.

6. *Consultation with land owners:*

- Yes, landowners are contacted prior to abandonment and deactivation of pipelines.

6.3 Mechanical Cleaning Suppliers

Here, interviews with mechanical cleaning (pig) suppliers (Quality Polly Pig Ltd. (QPP) and T.D. Williamson Inc.) are summarized:

1. *Pig types used for abandonment:*

- Light duty foam pigs for drying and picking-up residual moisture. Also, foam pigs are often used for evaluating line cleanliness;
- Medium density foam pigs and batch pigs for purging of line product.
- Medium density bristle foam pigs and cleaning pigs for line cleaning.
- Spray pig and squeegee pigs for inhibitor application.
- For a longer line and multiple abandonment jobs, a number of styles are available that incorporate cups (Figure 4a) and/or discs (Figure 4b) with available mounted carbon steel brushes.
- For a short line with a single abandonment job, a squeegee pig with criss-cross brushes is often requested (Figure 4c).
- Disc style pigs are very effective on dry lines (ex: natural gas).
- Cup/disc style pigs are very effective on wet lines (ex: crude oil).
- Disk and scraper pigs are recommended with chemical cleaning.

- For internally coated lines (large diameter natural gas pipelines), a squeegee pig with nylon brushes (instead of the carbon steel brushes) can be used. Nylon brushes are also available for the two cup brush (Figure 4d).
- In general, pig design relies mostly on experience and rules of thumb of the area operators.

(a) (b) (c) (d)

Figure 4 : Pigs with different designs and functions (a) Ultra Disc; (b) Power Disc; (c) Criss-Cross Wire brush; (d) Two-cup brush (Quality Polly Pig Ltd. Catalogue (Quality Polly Pig Ltd. (QPP), 2009)).

2. *<u>Cleaning pigs design for crude oil versus gas lines:</u>*
   - Pigs are typically designed for specific pipeline situations when the need arises.
   - Designs for gas and oil lines can occasionally converge and some pigs can be used for both. For instance, the same batching pig design may be used in either oil or a gas line.
   - However, certain pipeline conditions can warrant different pig designs that are more applicable in one product than the other. For example, a pig designed for wax removal would likely not be used in a gas line. A pig with a large amount of bypass designed for high velocity product would likely never be appropriate for a crude oil line.

3. *<u>The selection process of cleaning pigs:</u>*
   - End users/operators order cleaning pigs specifically for abandonment/discontinuation jobs.

- In general, pig selection depends on the pipe internal diameter (ID) and known condition of the line.
- Operators have a couple of options for pig selection:
  - From a pre-existing understanding of pigging, operators request the appropriate pigs that would be suitable for their application.
  - Work with pigging experts in the company and based on the specific line parameters, pigging suppliers can support the process to determine the best pig or fleet of pigs to achieve optimal results.
  - One pig manufacturer has *Pigging Technology* classes that operators may participate in to gain a better understanding of pig dynamics and aid in selection appropriate pig designs for specific pipelines.
- Progressive pigging is normally used when the internal conditions of a line are not known (e.g., pigging history is not available or if the line was transferred to a new operating company).
- Sometimes operators are faced with hardware limitations (e.g., only ball pig launcher, so they are limited to ball pig style only – unless incorporating costly upgrades to the system).
- Operators often ask for customized pigs (especially in terms of length and diameter). For instance, the number of mounted carbon steel brushes on these pigs is normally the customer decision (usually not more than 2 brushes).

4. *Minimum number of pig passes:*
   - This can be highly variable and is very dependent on the condition of the pipeline. An extremely clean pipeline may only need to be pigged once to determine that it is indeed clean. A pipeline that has a high contaminant loading may take dozens or more pig runs to completely clean. An operator may suspect the level of pipeline cleanliness based on flow characteristics and other parameters, but until a pig is actually launched and received, an operator will not know the extent of the cleaning that is required. Factors to consider would be:
     - Pipeline length;

- Amount of debris, scale, solids, particles, paraffin in the line and coming out of the trap after each run;
- Effectiveness of pigs used;
- Pig speed; and
- The quantity of bends, branches, valves in the line.

5. *Wear of cleaning pig:*
   - Pig wear, as well as the initial design, plays a large role in the effectiveness of a pig. This is highly dependent on the pipeline conditions. Some major operators of relatively slow flowing large diameter crude pipelines can run a pig for thousands of kilometers before it needs to be replaced. On the other end of the spectrum, high velocity dry gas lines may wear a pig out in as little as 30 kilometers.
   - Once a pig wears down to the point that is it smaller than the internal diameter (ID) of the pipe, it no longer provides effective cleaning. Pigs should always be replaced once the elements are smaller than the pipe ID. Certain design elements can be used during the initial design that can minimize wear and increase longevity.

6. *Assessment of cleaning pig effectiveness:*
   - Assessing pipeline cleanliness can be done through a few different means, none of which are 100% accurate but can generally give a good representation:
     - Evaluating the amount and type of debris that comes out of the receiver after a pig run. With experience and understanding the line parameters, it can be determined whether it is an acceptable quantity or if another pig pass is required.
     - Installing 'Top of the Line Coupons'. A small coupon, inserted into a Thread-O-ring fitting, can be removed and inspected at prescribed intervals. The information gathered can give the operator a real life representation of line condition.
     - Inspecting pipe sections that have been removed due to corrosion or external damage.
     - Periodic product sampling to determine microbe population.

7. *Shortcomings with current cleaning technologies:*
   - While cleaning pigs are an integral part of any pipeline maintenance program, it should be as well a part of a holistic program that also includes other key items. These include surfactants, biocides, corrosion inhibitors and cathodic protection systems. Mechanical cleaning pigs serve to enhance all of these maintenance items. For example, corrosion inhibitors cannot effectively reach corrosion cells at the bottom of pits if those pits are packed with paraffin. Cleaning pigs can remove that paraffin while V-JET®-by T.D. Williamson-spray pigs (Figure 5) can effectively apply that inhibitor to the top of the pipeline.

Figure 5: V-JET® Corrosion inhibitor pig (T.D. Williamson Inc., 2015)

8. *New technologies/ideas in pig design:*
   - One of the main technologies developed and utilized in the last few years have been pencil brushes. One operator is also currently developing pig designs that are more specifically focused on cleaning wax. Many of the special pig designs are developed hand in hand with operators for specific pipeline situations, while always assessing market needs to determine new designs and ideas to continue driving forward the needs for safety and pipeline efficiency.

In addition, ROSEN Group[5] provided a program suggested by their pigging experts for the cleaning of a pipeline prior to abandonment. The program reads as follows:

- "*The complete crude oil shall be released down to atmospheric pressure.*

[5] Communication with ROSEN.

- *The first cleaning run should be a transmitter scout pig with gauge plate propelled with nitrogen. This will serve as the first removal of main debris and confirm whether the line is completely piggable.*
- *Next pig is a brush pig to remove and loosen all adhesive debris - depending on the results, repeat or start with the next pig. Propelling medium is nitrogen.*
- *A magnet pig run will then collect all magnetic debris - depending on the results repeat or start with the next pig. Propelling medium is nitrogen.*
- *Run two batching pigs with a surfactant batch. This batch will flush not only the mainline but also all dead ends (offtakes etc.). Depending on the results repeat or start with the next pig. Propelling medium is nitrogen.*
- *After this run on both ends and on all high points, the remaining hydrocarbons residue shall be measured.*
- *If the hydrocarbon residue is below or close to the allowable value, the pipeline can be purged with dry air until the line is clean.*
- *In case of a higher amount of hydrocarbons, a cleaning pig shall be run until the line is clean.*
- *In case of increased remaining deposits like scale, a cleaning run can change from standard cleaning to a more aggressive pig like HDCP [Heavy Duty Cleaning Pig] or descaling pig until the line is clean.*
- *In the end, the line is depressurized, free of liquid, filled with dry air and the hydrocarbon residues are below the permitted values.*

All local regulations and guidelines have to be considered. In some countries a closing inspection run is necessary, to identify potential or uncertain risks for possible re-qualification, reconditioning."

The previous procedure along with the supplier's surveys clearly suggests that progressive pigging (i.e., pigging with more than one type of pigs) is highly important in order to ensure a high level of cleanliness in the pipe. For aggressive cleaning, pigs with mounted steel brushes would be used; on the other hand, a foam pig would be used for removing residual contaminants. The procedure also highlights the importance of sampling and measuring for residual contaminants.

It should be noted that having no visual evidence of pipeline sediment on the cleaning pig does not necessarily suggests that the pipeline is free of debris. For example[6], a crude oil pipeline that was cleaned using five cleaning pigs showed minimal sediment in the trap after the first pig pass suggesting that the pipeline was clean. An ILI tool was then launched in a refined light product and sediment was observed at the traps upon receipt. In conclusion, one cannot rely on the cleanliness of the trap and visual observations to determine whether the line is clean or not. Assessing the cleanliness of a crude oil pipeline will likely require alternative techniques to visual observation of sediments at the receiver trap.

6.4 Chemical Cleaning Suppliers

Here, interviews with chemical cleaning suppliers (Baker Hughes and GE Water & Process Technologies) are summarized:

1. *Common chemical cleaning products used in pipeline:*
   - Operators have a range of targets for cleanliness of abandoned pipelines, therefore a variety of chemicals maybe utilized. Common chemicals used are:
     - Solvents, dispersants and surfactant based chemicals;
     - Biocides;
     - Corrosion inhibitors;
     - Water based cleaners; and
     - Hydrogen sulfide and oxygen scavengers.

2. *Cleaning chemicals for crude oil vs. gas:*
   - In general, cleaning chemicals will vary from one line to another.
   - An optimized chemical cleaning plan will include testing of a variety of chemicals on deposits obtained from the pipeline when performing mechanical pigging. In cleaning oil pipelines it is important to use solvents to address the high potential wax in the system and then testing them to confirm that they have not become saturated, thus giving a strong indication that no wax remains.

[6] Communications with Enbridge Pipelines, Incorporated.

3. *Cleaning chemicals for the purposes of abandonment versus for a routine cleaning:*
   - In general, there is should be nothing harmful to the environment after cleaning.
   - This is dependent on the target cleanliness, particularly regarding leaving the pipeline oil wet versus water wet. Also, the general criteria for waxes are often substantially different. Operational pipelines tend to be cleaned for control of waxes, while for abandonment the target should be wax removal.
   - For pipelines falling under the NEB's jurisdiction, the consensus is moving towards leaving water wet surface with low levels of hydrocarbon present. This is a stringent criterion that requires surfactant based chemistries and water rinsing to obtain.

4. *Main purpose of chemical cleaning:*
   - The main purpose of chemical cleaning is to remove hydrocarbon deposits and debris, iron deposits, organic material and kill bacteria. Chemical cleaners are also used for the purpose of improving penetration into solid deposits, loosening the deposits, and lifting the deposits off the pipeline wall.
   - Hydrocarbons deposits and debris are removed for the purposes of:
     - Maintaining flow;
     - Obtaining inspection data (high volumes of debris require integrated chemical, mechanical and gel pig cleaning train designs);
     - Enhancing inhibitor/inhibition chemical application;
     - Protecting the environment for abandonment;
     - Conserving the line (spec varies dependent on change of service).
   - Scale removal is prevalent in water and disposal lines and is required to maintain flow or acquire inspection data.

5. *Residual contaminants left from the cleaning chemicals:*
   - All chemicals will leave residual contaminants. Even water based cleaners will have surfactants derived of petroleum products or have a similar molecular structure to those derived of petroleum products; therefore high specification cleaning requires rinse stages.
   - Biocides are flushed out prior to abandonment due to their environmental impacts if released.

- A corrosion inhibitor can be used to provide a film that can prevent corrosion.

6. *Determining the amount of cleaning chemicals:*
    - The following factors will determine the amount the chemicals to be used in a pipeline: its history, condition, age, length, diameter, medium inside the pipeline, analysis of samples, and review of inspection data, as well as microbiological activity and contaminant levels.
    - Ideally chemical slugs should be run during operation before the line is removed from service and analyzed to confirm they have not become saturated with debris (to determine if additional batches are required).
    - Online cleaning is more cost effective than offline cleaning and allows for removal of hydrocarbon debris/waxes at a fraction of the cost. If planned correctly only an additional chemical slug with the final displacement will be required to abandon oil wet.

7. *Main properties/characteristics required for chemicals:*
    - The most important properties for cleaning chemicals are:
        - Be dispersible in the carrier.
        - Break down the deposits (solvency of some components of the deposit).
        - Penetrate the deposits.
        - Aid in suspension of solids.
    - Cleaning chemicals are effective in removing organic and iron deposits.
    - Biocides have a short half-life, but are effective in killing organisms.
    - Corrosion inhibitors (filming inhibitors) need to have effective and tenacious filming properties.
    - Selection of an appropriate chemical cleaner is based on solids compatibility, ability to penetrate and suspend deposits (while minimizing viscosity of cleaner/solids mixture), and ease of separation of cleaner/solids for final reuse or disposal.

8. *Testing cleaning chemicals:*
    - Both companies conduct in-house testing for chemical performance and have testing facilities to select the correct chemical or combination of chemicals for particular

applications. For large cleaning projects a pipe sample is recommended for sample loading and testing.

9. *Assessing the effectiveness of the cleaning chemicals:*
   - Multi-stage pig trains or multiple runs are performed and Gradient Testing (changes between runs or stages) is performed including debris loading, remaining chemical activity, opacity or other test determined applicable during the initial testing and job design.
   - Chelation[7] and emulsification potential for water based cleaning chemicals.
   - Both minimum biocide concentration and speed to kill are considered when evaluating biocide efficacy.

10. *Any shortcomings with current chemical cleaning technologies:*
    - Pipeline pigging is critical for effective pipeline cleaning with chemicals.
    - The potential always exists for localized areas of debris/deposits to remain in the pipeline.

7 CURRENT PIPELINE ABANDONMENT PRACTICES

In this section, AITF conducted a scoping study for pipeline abandonment procedures. The objective is to determine if any guidelines currently exist that are used by pipeline operators. As mentioned earlier, most of the transmission pipeline operators have limited experience related to pipeline abandonment and/or decommissioning- due to the lack of need- and, therefore, do not have specific programs or procedures. The companies that do not have a major abandonment project will simply follow the guidelines of the pipeline act and the CSA Z662 standard. This was confirmed from the following collected notes from Kinder Morgan related to one of their abandonment projects (the decommissioning and replacement of the McLeod River HDD pipe). The decommissioning involves decommissioning in place and decommissioning by removal

[7] A chelating agent is a molecule capable of binding to a metal ion and bringing the metal ion into solution.

(more details on this project can be found on the NEB's website). In general, Kinder Morgan is following the CSA Z662 standard and the decommissioning process will roughly include the following steps[8]:

- Remove service fluid (crude oil) using a purging pig (1st purge);
- Perform a 2nd cleaning by a foam pig;
- Cap and blind the end;
- Purge and blanket with Nitrogen under a pressure of 10 psi;
- Keep the cathodic protection on; and
- Keep inspecting and monitoring the line by monitoring the pressure transmitters, the cathodic protection, and the environment to ensure the integrity of the pipeline is intact.

It should be noted that the decommissioning process for the McLeod River case does not include the use of chemical cleaning nor corrosion inhibitors.

A more detailed cleaning program for decommissioning is also provided by Enbridge (Enbridge Pipelines Inc., 2014). The company submitted an application in November 2014 to the NEB for the proposed replacement of Line 3. The original line consists of 0.86 m (34 inch) diameter pipes and will be replaced with a 0.914 m (36 inch) diameter one. Line 3 carries crude oil and is 1067 km in length. Some of the relevant sections from their cleaning program (the full application is on the NEB's website (National Energy Board (NEB), 2015)) are shown below.

Enbridge would do their assessment of the cleanliness level based on the amount of film thickness left in the pipeline after running the cleaning pigs. The cleaning program is designed to minimize the residual film of the remaining product/cleaning chemical mix left on the internal surface of the pipe. The company presents two potential approaches to perform the fluid displacement and cleaning of the pipeline:

- "*Combine the displacement and cleaning programs into one operation;*" or
- "*Separate the displacement and cleaning programs into two operations.* "

[8] Personal communication with Kinder Morgan Canada.

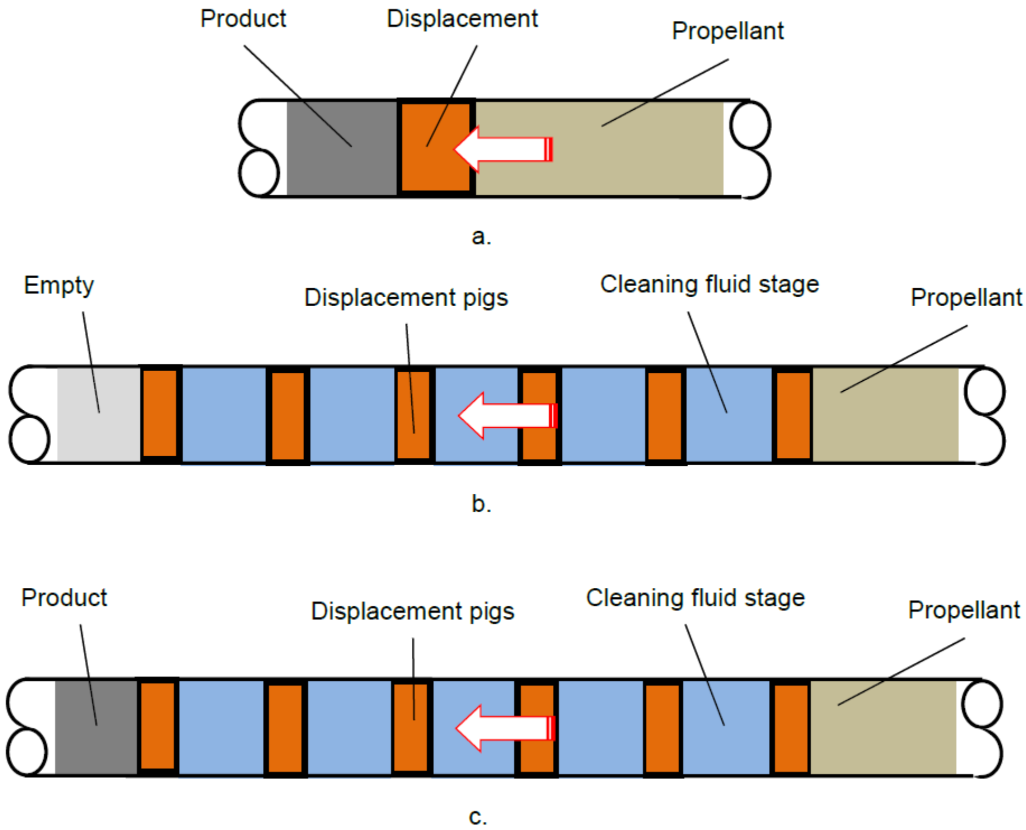

Figure 6: Schematic of possible displacement and cleaning programs (a) separate displacement of crude oil from pipeline and; (b) separate cleaning program; or (c) combined displacement and cleaning program (Enbridge Pipelines Inc., 2014).

The two approaches are schematically illustrated in Figure 6. The cleaning phase consists of number of pigs separated by water stages. The pigs might have brushes to increase their effectiveness. Each pig will leave a residual film behind it (calculated as 2.1 microns (0.08 mils) but taken to be 25.4 microns (1 mil) for conservatism). The residual film was calculated using the following formula (Hiltscher, Mühlthaler, & Smits, 2003):

$$s = 0.679 \times \left(\frac{u}{p}\right)^{\frac{2}{3}} \times R_1^{\frac{1}{3}} \times \eta^{\frac{8}{21}}$$

Where:	u [m/s]	Pig speed
	p [N/m^2]	Propellant pressure
	R [m]	Mean radius of curvature

η [Pa.s] Dynamic viscosity of the product

s [m] Residual film thickness

Using the previous formula, the residual film thickness could be easily determined from the knowledge of the pig speed, line diameter and pressure, and the viscosity of the transported commodity. As shown by Enbridge cleaning program, the film will have a concentration of 100 % product after the very first pig. The film will be then mixed with water and further diluted. The final amount of oil left in the pipe wall in the residual film will depend on the mixing efficiency with water and film thickness. Cleaning as a function of number of water stages and mixing efficiency is illustrated in Figure 7. The water that the company would use for cleaning does not include corrosion inhibitors, since they are not biodegradable, but rather an "*environmentally acceptable cleaning agent (s)*".

In order to illustrate the importance of using water stages as a part of the overall pipeline cleaning, the following simple calculations are presented. Based on the total length of the line, 1067 km, and the diameter of the pipeline, 0.86 m, one can calculate the surface area of the pipeline as:

$$SA = \pi \times D \times L = 3.14159 \times 0.86 \times 1067000 = 2822786 \text{ m}^2$$

The volume of the resiudal film becomes (based on a conservative estimate of 25.4 micron):

$$V_r = SA \times film\ thickness = 2822786 \times 25.4 \times 10^{-6} = 73.22276 \text{ m}^3 = 73222.76 \text{ L}$$

Therefore, there will be around 68 L/km (68 mL/m) of products left inside the pipeline without efficient mixing and water stages. However, as Enbridge shows in its proposed cleaning program, when a number of water stages are used and assuming a mixing efficincy between 80 - 90 %, the volume of products left inside the pipeline is estimated to drop to 7.2 mL/km (which corresponds to removing 99.988 % of the residual product from the pipeline). These calculations emphasis the importance of including water stages during the final cleaning steps.

With respect to residual contaminants, there is no history of PCBs or NORMs in the products carried by Line 3 according to the company. However, Enbridge will be sampling to confirm that no PCBs or NORMs are present in the pipeline. If they are present, the company states that it would perform an assessment to mitigate the risk of the aforementioned contaminants. As of now, the cleaning program does not mention on-site testing.

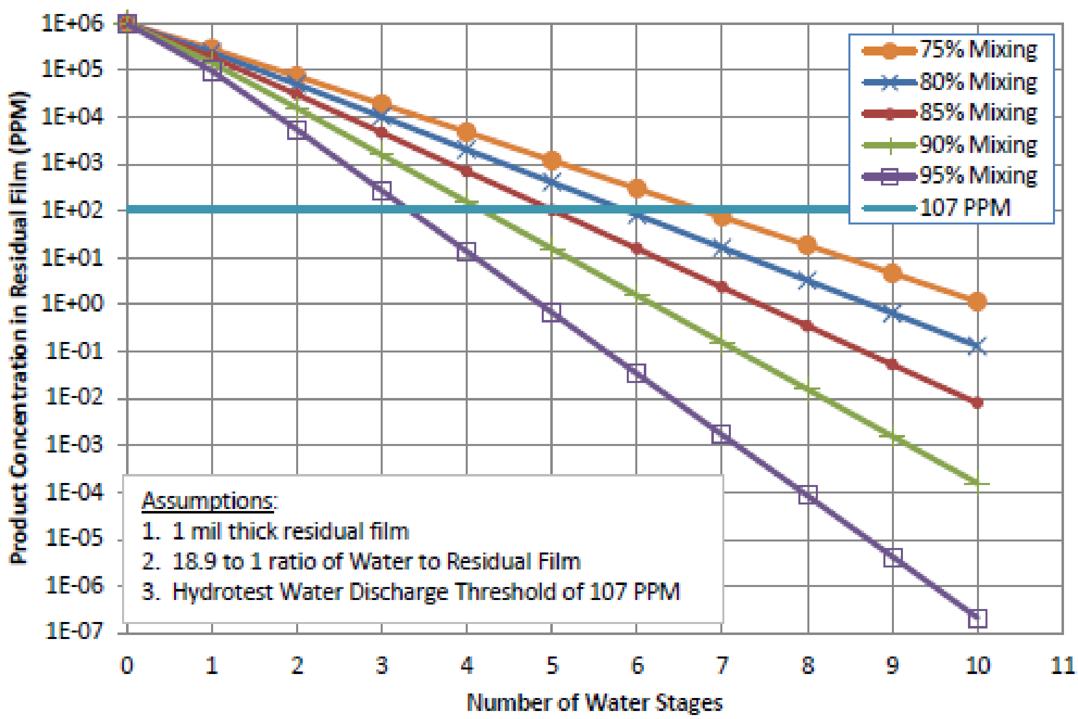

Figure 7: Pipeline cleaning as a function of water stages and mixing efficiency (Enbridge Pipelines Inc., 2014).

Next, the abandonment and discontinuation guidelines presented by Canadian Natural Resource Ltd. (CNRL)[9] are also presented herein. The company has a special program titled "the Pipeline Abandonment and Discontinuation Program" within the company's North America Exploration and Production operations. Although CNRL is an upstream company and as such is out of this study's scope, it is nevertheless beneficial to examine all available abandonment procedures. The program, as the title suggests, is concerned with pipeline abandonment and discontinuation in order to meet regulatory requirements, protect the environment, and reduce liabilities. According

[9] Through personal communication with CNRL

to the company's website, a total of 1289 pipelines were either abandoned or discontinued in Alberta, British Columbia, and Saskatchewan in 2013. This number was 899 in 2012.

In the next paragraphs, a review of the company's program is given. For pipeline abandonment, the company identified the following procedure:

1. *"Pig with a fresh water slug or purge with air or inert gas. No chemicals or inhibitors shall be added to the purge fluids …… Remove any surface equipment, unless the equipment is located within the boundaries of a facility that will continue to have other licensed equipment operating after the pipeline abandonment procedure.*
2. *Cut off the pipeline below grade at pipeline level, unless it is located within the boundaries of a facility that will continue to have other licensed equipment operating after the pipeline abandonment procedure."*
3. *Permanently plug or cap all open ends by mechanical or welded caps.*
4. *Identify all ends with a permanent tag that includes the licensee, license and line number, other end points and date of abandonment. NOTE: It is not required to disconnect all licenced segments UG in a gathering system that is being abandoned.*
5. *Disconnect the pipeline from the cathodic protection system.*
6. *Risers must be removed from the site at time of abandonment if there are no other operating pipelines*
7. *Risers should not [be] removed from operating sites until such time as all facilities are abandoned, then the risers can be removed safely."*

It should be noted that the previous program is still under some modifications and has not been finialized[9]. For pipeline discontinuation, the guidelines distinguish between internally bare, steel pipelines and internally coated, non-steel pipelines and differ slightly from the abandonment guidelines. For instance, the guidelines suggest the use of chemical treatment for internally bare steel pipelines, with three chemical treatment options: a) methanol batch (preferred option), b) glycol batch, and c) corrosion inhibitor + diesel or condensate batch. On the other hand, for internally coated pipelines or for pipelines that are not made out of steel, the discontinuation guidelines suggest to use foam pigs instead of disk pigs (to prevent harming the coating or the pipeline) but do not mention the use of chemicals or inhibitors.

It is clear that the procedures for discontinuation and abandonment are slightly different from one another. In general, the outlined abandonment requirements are similar to the guidelines that exist in the Alberta pipeline Act and also to the ones stated in the CSA Z622-11 standard. On the other hand, the discontinuation requirements contain more details, especially on the pigging, than the abandonment ones. It should be noted that the company recognizes the negative effects of adding inhibitor and chemicals (since they are not biodegradable or environment friendly); however, it seems that sampling to check on the levels of residual contaminants is not a part of the procedure.

8 DETECTION AND TESTING OF WASTE AND CONTAMINATS

8.1 Current Pigging Waste Testing Practices

The current testing practices for cleaning waste in pipelines are explored in this subsection. Pipeline operators perform regular cleaning for pipelines in service. It was found that field testing is not performed on pigging waste, instead the samples are usually sent to testing laboratories for analysis in order to determine the elemental composition and concentration of components in the recovered waste, among other parameters. It is more economic to send samples to laboratories as no equipment or mobile laboratory costs would be incurred. Based on the information received from personal communications with testing laboratories[10], the following series of tests are typically performed on pigging waste samples (Table 11).

Table 11: Tests Performed on Pigging Waste Samples.

Parameter	**Test Method**
Anion Presence	Spot test for Chloride, Sulphide, Sulphate, Carbonate
Asphaltene	ASTM D3279/D6560
C30+	GPA 2013
High Temperature Simulated Distillation	ASTM D7169
Loss on Ignition	Standards Method 254
Metals ICP	EPA SW-846-6010C
Solubility	In house method

[10] Personal communication with AGAT Laboratories, Maxxam Petroleum Technology Center, and ALS.

Wax	UOP 46M
Elemental Analysis/ Chemical Characterization	XRD/XES
Elemental Analysis/Chemical Characterization	Dean Stark (Reference Method 1.00, 1983)
Flash Point	ASTM D3828, D56 or D93
Oil & Grease Breakdown	Reference Method for the Canada-wide Standard for Petroleum Hydrocarbons in Soil – Tier 1 Method
PCBs (leachable)	EPA 3510/8082-GC/ECD
NORMs	EPA 901.1/903.1/904.0 & ASTM D3972
Chlorides (leachable)	EPA 1311/300.1

8.2 Testing For Residuals

Pipelines considered for abandonment will most likely undergo routine cleaning until the end of service date is reached and any product remaining would be displaced. This should leave a very small amount of residue in the pipeline. A summary of substances that may be released by abandoned oil and gas pipelines is reproduced in Appendix C. At the moment, there are no regulations for the maximum allowable level of residual contaminants remaining in abandoned pipelines and thus operators are left to prepare their own abandonment procedure and determine the acceptable level of cleanliness. Nevertheless, one of the main concerns regarding abandoned pipelines is the potential release of contaminants to the groundwater or soil. In order to establish some guidelines regarding contaminant levels, it would seem reasonable to use pipeline hydrostatic test water guidelines as a starting point. If the test water from hydrostatic testing is to be released to the ground, it has to be first analyzed in order to ensure that the water meets the requirements of the "*Code of Practice for the Release of Hydrostatic Test Water from Hydrostatic Testing of Petroleum Liquid and Gas Pipelines*" (Alberta Government, 1999). Some of these requirements read:

a) "The sum of total purgeable hydrocarbons and total extractable hydrocarbons must be 100 mg/L or less; and"

b) "The EC_{50} of a Microtox test shall be greater than or equal to 100%."

In addition, the parameters in Table 12 must be monitored and the limits in the table cannot be exceeded in order to release the test water to receiving water.

Table 12: Limits for Release to Receiving Water (Alberta Government, 1999)

Parameter	**Limit (in mg/L unless otherwise stated)**	**Limit where release involves mixing of 2 or more parts receiving water for every 1 part hydrostatic test water (in mg/L unless otherwise stated)**
TSS	Less than or equal to 20 mg/L above ambient receiving water level	Less than or equal to 20 mg/L above ambient receiving water level
Benzene	0.3	0.6
Ethylbenzene	0.7	1.4
Toluene	0.3	0.6
Xylenes	0.3	0.6
Free chlorine residual*	0.1	0.2
pH	6.0 to 9.5 units	6.0 to 9.5 units
Iron, dissolved	1.0	2.0
Oil and Grease	No visible sheen	No visible sheen
Additives	Non-toxic concentration	Non-toxic concentration
Acute Toxicity test using Rainbow trout, or Daphnia Magna, or Microtox	LC_{50}, EC_{50} or IC_{50} greater than or equal to 100%	LC_{50}, EC_{50} or IC_{50} greater than or equal to 100%

*Free chlorine residual monitoring is only required when hydrostatic testing involves the use of chlorinated products or chlorinated water.

Through consultation with pipeline operators and literature review, it turns out that this approach has been used (Mark S. Keys, 1993) or is planned to be used (Enbridge Pipelines Inc., 2014) for pipeline cleaning/abandonment programs.

To prepare a comprehensive list of test methods for the detection of residual contaminants prior to abandonment, relevant tests from the list of routine testing on pigging waste along with tests for relevant substances from the table of potential contaminants could be added to the list of tests required by the hydrostatic test water guidelines. A number of tests on those lists would not be applicable since there should be little product left after displacement. A list of recommended test methods to analyze for residual contaminants in the recovered fluid and on the pipeline surface have been compiled as shown in Table 13 and Table 14, respectively.

Table 13: Recommended Test Methods for Residual Contaminants in Recovered Fluid

Contaminant	Test Method
NORMs*	Geiger counter
PCBs*	EPA 3510/8082-GC/ECD
TSS	2540 D. Total Suspended Solids Dried at 103 - 105 °C
BTEX	EPA 5021/8015&8260 GC/MS & FID and EPA 3510/CCME PHC CWS-GC/FID
pH	pH Meter
Iron, dissolved	3500-Fe B. Phenanthroline Method
Total Hydrocarbons (Oil and Grease)	ASTM D7678
Additives	Method of detection specific to the additive
Acute Toxicity test using Rainbow trout, or Daphnia Magna, or Microtox	Environment Canada Report EPS 1/RM13, July 1990 or Environment Canada Report EPS 1/RM14, July 1990 or Environment Canada Report EPS 1/RM24, November 1992
PAHs	EPA 3510/8270-GC/MS
Carbonates/bicarbonates	Alkalinity
Total Sulphides	APHA 4500-S
SRB/APB Bacteria Concentrations	Culturing Techniques (e.g., BART Test Kit)
Mercaptans and H_2S	UOP 163
Total Organic Carbon and Total Inorganic Carbon	TOC and TIC
Heavy Metals (34 elements)	ICP-MS
Total Purgeable Hydrocarbons	Purge and trap gas chromatography (EPA Preparation Method 5030)
Total Extractable Hydrocarbons	Dichloromethane-extractable (EPA Preparation Method 3540A, EPA SW-846)

Table 14: Recommended Test Methods for Residual Contaminants on the Pipeline Surface

Deposit Analysis Protocol (Swab Inside Surface of Pipeline) and Pipeline Atmosphere	
Contaminant	**Test Method**
Total Hydrocarbons (Oil and Grease)	ASTM D7678
PAHs	EPA 3540/8270-GC/MS
Heavy Metals (34 elements)	ICP-MS
PCBs*	EPA 3550/8082-GC/ECD
NORMs*	Geiger Counter

*If there is no history of NORMs or PCBs in the pipeline to be abandoned, an assessment could be done at the initial cleaning stage to determine if they are present. If they are not present, testing for these contaminants would be discontinued.

8.3 *Commercially Available Field Detection Instrumentation*

In-field analysis has traditionally been used for remote locations but it is now used more frequently for expedited results. While not all analysis can be done in the field, there have been many advances with instrumentation to allow more portability. This section will provide a brief market overview of existing portable instrumentation that could be used for testing residual contaminants in pipelines that are to be abandoned. The instrumentations shown hereafter are solely selected to give a glimpse of products that exist in the market and not for any other purposes.

PCB contamination through the use of compressor oils at compressor stations may be present in older pipelines. PCBs do not readily breakdown in the environment due to their stability and are of concern due to their toxicity. The presence of PCB residue found in a pipeline could easily be assessed using field testing swab kits such as Dexsil's PCB wipe kit in conjunction with the L2000DX analyzer (Dexsil L2000DX PCB/Chloride Analyzer System LP-200, 2015). This quick onsite assessment could be done initially to eliminate the need for further PCB testing.

Pipeline sludge may become contaminated with radon decay products potentially contaminating cleaning pigs. The presence of NORMs in pipeline residue may be disturbed during abandonment cleaning processes increasing the risk of exposure. Geiger counters are portable and can be used in field for detection of NORMs for prompt results. There are a wide variety of field Geiger counters available with various features and options but as a minimum the counter should be sensitive to low level detection of alpha, beta, and gamma radiation.

Hydrocarbon residue has been identified in deposits on internal pipeline walls (Thorne, Basso, & Dhol, 1996). Polycyclic aromatic hydrocarbons (PAH) and total petroleum hydrocarbons (TPH) can be tested in field using SiteLab's TD-500D and UVF-3100A/D Analyzers (SiteLab, 2015), shown in Figure 8. The hand held TD-500D could be used to detect PAH and TPH in pipeline residue on-site during the abandonment operation and could be used during the cleaning runs to estimate residual contamination. The UVF-3100A/D is slightly larger and requires an external power supply but could also be brought onsite to a mobile laboratory; it can be used to test for gasoline range organics (GRO), extended diesel range organics (EDRO), extractable petroleum hydrocarbons (EPH), TPH, and Target PAH.

Flame ionization detectors and electron capture detectors are quick quantitative ways for analysis of specific compounds. For field testing, having both these instruments available would be ideal. Thermo Scientific's TRACE™ 1300 Gas Chromatograph (Figure 9 (a)) uses interchangeable instant connect injectors and detectors allowing the user to switch either "in minutes or without tools" for unprecedented flexibility (Thermo Scientific, 2015). The versatility of this Gas Chromatograph would make it ideal for field work.

ICP-MS have primarily been limited to in laboratory use but recent advances in technology have allowed for bench top versions of the previously larger footprint instruments. PerkinElmer's NexION 300 ICP-MS (Figure 9 (b)) is a bench top instrument that can be adapted to mobile laboratories if vibration is minimized.

(a) (b)

Figure 8: Field instrumentation for testing hydrocarbon residues: (a) TD-500D; (b) UVF-3100 (SiteLab, 2015)

(a) (b)

Figure 9: Field detection instrumentation (a) TRACE 1300 Gas Chromatograph (Thermo Scientific, 2015); (b) NexION 300 ICP-MS (PerkinElmer, 2015)

9 CONCLUSIONS

The main objective of this pipeline abandonment study was to report on the effectiveness of pipeline cleaning methods, and the residual contaminants in crude oil and natural gas lines and testing techniques and instrumentations to analyse and detect these residues. In addition, different aspects of the abandonment process were also discussed. All the information gathered and reported herein was based on stakeholder engagements (interviews) and literature search. AITF interviewed pipeline operators, mechanical and chemical cleaning vendors, and industry regulators to collect information on current practices used in the pipeline abandonment process along with the pertinent legal requirements.

As previously reported, there are no guidelines or standard procedures for pipeline abandonment that the industry has adopted; instead, each pipeline operator has internally developed guidelines and cleaning programs for abandonment, if applicable. These internal guidelines vary between operators and some are well-established and detailed procedures for abandonment process, while others are more high-level guidelines that allow for discretion during the abandonment. This variance in internal guidelines reflects the varying degree of abandonment experience between transmission pipeline operators. Currently, some operators do not have the need to develop lengthy guidelines or procedures as their assets are not scheduled for abandonment in the immediate or near future. Within this study, the most comprehensive cleaning program reviewed was developed by Enbridge Pipelines, Incorporated as part of their Line 3 replacement project.

Pig suppliers and manufacturers seem to agree on general guidelines for pig selection and some have even developed their own guidelines specifically for pipeline abandonment. In general, good choice of pig design is a key factor in achieving the intended cleaning levels. Therefore, consultation with pig suppliers would be beneficial for most operators to ensure an effective cleaning program for the pipeline in consideration of the line's operating history.

The use of chemical cleaning in conjunction with pigging is necessary to break down scales to make the pigging process more effective. The effectiveness of any chemical cleaning program will highly depend on the effectiveness of the pigging program associated with the overall cleaning process. It is important to note that cleaning chemicals will inherently leave behind residual contaminants as noted by the engagement with the chemical cleaning suppliers.

From the engagement with pipeline operators, pigging waste samples would not be tested on-site, instead samples are sent to laboratories for analysis and testing. A market review showed the existence of on-site instruments that can detect a range of different substances. However, there is a lack of portable instrumentation that can detect and measure individual BTEX components, total suspended solids, total extractable and total purgeable hydrocarbons or acute toxicity.

The interviews that were conducted with the NEB and the AER showed that the acts and regulations pertaining to pipeline abandonment are general and do not have specific criteria for the level of cleanliness of a pipeline, nor define the acceptable levels of contaminants that could remain in the pipeline. Within Canada, the regulations are slightly different from one jurisdiction to another, but, in general, the process is more controlled under the NEB jurisdiction. Furthermore, effective cleaning is left to the due diligence of operators, at least under the AER jurisdiction, as third-party inspection is not mandated. Also, the regulations do not necessarily differentiate between leaving the abandoned pipeline in place and removing it to a storage site.

10 POTENTIAL FUTURE PROJECTS

Potential future projects that emerged out of this study are next outlined.

1. *Develop guidelines for pipeline abandonment.*

It is recommended to develop guidelines, based on the information gathered in this report for pipeline abandonment. For instance, the guidelines could include pipeline cleaning methods and the detection of residual contaminants in abandoned pipelines, among other subjects. The guidelines will aim at standardizing the process of pipeline abandonment throughout the industry. Thus, it will have a positive impact on the O&G industry, and will prove to be beneficial to pipeline operators (especially the ones with limited experience in pipeline abandonment), landowners, regulators, and other stakeholders engaged in the process. Enbridge's cleaning program for the decommissioning of Line 3 might serve as a starting point towards serving this purpose.

2. *Set criteria for the allowable levels for residuals in an abandoned pipeline*

It is crucial to ensure that the amounts of residuals left inside the pipeline are within permissible limits such that there would be no impact to the environment if the integrity of the abandoned pipeline was compromised. It is therefore recommended that such criteria be included in the standards (e.g. the CSA Z662) and in the regulations (if applicable). The allowable levels of residuals could be put in terms of an allowable residual film thickness left on the pipeline, with a maximum concentration of the original products in the final film left in the line. For the moment, pipeline hydrostatic test water guidelines could be used as a starting point for establishing allowable levels of contaminants in crude oil and natural gas pipelines.

3. *Pipeline cleaning using progressive pigging and bio-degradable chemicals*

Progressive pigging is an important step in ensuring a higher level of cleanliness. Using various pig designs with different brush types and/or brushes and disks combinations is essential in removing high volumes of deposits and debris. Mechanical cleaning programs prior to an in-line inspection (ILI) could be adapted for pipeline abandonment as the lines should be in a good clean state to prevent damaging the expensive tool and increase the confidence in the collected data.

Bio-degradable chemicals that pose no potential risk on the environments are recommended to minimize the risk of leaving behind contaminants in the pipeline. It is also recommended to implement water stages to rinse any residuals. Due to environmental concerns, corrosion inhibitors should only be used with deactivated/discontinued and not abandoned pipelines.

4. Case study Enbridge's Line 3 decommissioning project

Enbridge decommissioning of Line 3 provides a great opportunity to case study major pipeline abandonment/decommissioning project. Third party witnessing of the process and the approach and lessons learned from this project could be used as a foundation for an industry best practice. For instance, to validate the Enbridge calculations that indicate a residual of less than 7.2 mL/km of oil after cleaning using water stages, among other aspects of their cleaning program.

5. Pilot scale experiment for pipeline abandonment

Research directions should include modelling or simulating the abandonment process. This includes the assessment of combined mechanical and chemical cleaning programs in removing residual contaminants from a pipeline section and measuring the thickness of the residual film left. The knowledge obtained from this pilot experiment will provide input to models that predict thickness of residual films and hence estimate the volume of products left after cleaning a pipeline.

6. Field testing and sampling for contaminants

A rapid, field measurement will be critical for pipeline abandonment operations as field crews will need to determine the cleanliness levels at site. Checking the allowable levels of residues remains a very crucial step in ensuring that the abandoned pipe would be left clean and free of potential contaminants. In fact, sampling for residual contaminants could be the decisive stage in the pipeline abandonment process that supports that the cleaning programs was successful and potential risk of contaminants is sufficiently low. Three tests are recommended to be performed on site: NORMs, PCBs, and TPH/PAH. Field testing for NORMs and PCBs at the initial stages of cleaning would allow for this testing to be eliminated for the rest of the pipeline saving time and resources. Testing for TPH/PAH between pigging runs would enable operators to gauge the effectiveness of pigging. The development of field instrumentations to perform the testing from Tables 11 and 13 would be recommended.

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12 APPENDICES

Appendix A – Cleaning Guidelines from the NEB [11]

A.1 General Considerations

The operating history of the pipeline to be abandoned should be reviewed to enable the planning of the specific cleaning procedures required for abandonment. Information such as oil/gas analysis, piping modifications, operating flow records, records of anomalies, and maintenance records may provide some insight into additional work needed to develop an effective pipeline cleaning plan. The owner/operator should ensure that there are adequate sending and receiving traps in place. This may require the use of temporary assemblies. If the pipeline in question is part of a larger system, the section to be abandoned should be physically disconnected upon completion of the cleaning process. Safety precautions appropriate to the in-service product hazards (i.e. flammability and explosivity of hydrocarbons, toxicity of sour products) must be established throughout the activity. For gas pipelines, any residual gas should be vented or flared once the pressure in the pipeline has been reduced to the extent possible using operating facilities or a pull down compressor. The residual gas should be monitored for signs of liquid.

For liquid pipelines, before line flow ceases, a sufficient number of scraper pigs should be run through the line to remove the bulk of any solids or waxy build-up. As illustrated by the figure below, a batch of solvent-type hydrocarbons such as diesel fuel or condensate inserted between two scraper pigs is recommended as an effective method of reducing solids or waxy build-up. This process should be repeated until solids can no longer be detected on the pigs as they are removed from the receiving trap. Specialized chemical cleaning may be required if the routine cleaning method described is not successful, if the pipeline is known to have an unusually high contamination level, or if unusually high cleanliness standards are to be met. Special precautions must be exercised when the pipeline is opened up to control vapour hazards of flammability, explosiveness, and toxicity (e.g. hazardous compounds such as benzene).

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[11] Reproduced from (Canada. Canadian Association of Petroleum Products, Canadian Energy Pipeline Association, Alberta Energy and Utilities Board, & National Energy Board, 1996)

A.2 Cleaning Methods for Natural Gas Pipelines

A stiff rubber scraping pig should be pushed through the pipeline (at a constant speed consistent with the pig manufacturer's recommendation) using nitrogen or some other inert gas to prevent explosive mixtures. Free liquids pushed ahead of the pig may be either pushed into the downstream pipeline section or collected in a containment tank designed and isolated according to prevailing local guidelines, for disposal in accordance with area legislation or local by-laws. This process should be repeated until free liquids are no longer evident by visual inspection. Low areas of the pipeline should be checked for the collection of liquids or other contaminants.

After these initial pigging runs, the pipeline should be checked for cleanliness. If contamination is evident, the pigging procedure should be repeated using a slug of solvent between two pigs. As with the free liquids, the solvent should be collected in a containment tank and disposed of in accordance with area legislation or local by-laws. Solvent fumes should be purged with nitrogen or a similar inert gas.

A.3 Cleaning Methods for Liquid Pipelines

Following completion of the initial in-service cleaning efforts, a final cleaning step should be done in conjunction with line evacuation. The following procedure is commonly used, although many variations exist which should be considered. Consultants specializing in the cleaning of contaminated facilities can advise and provide plans for both normal and unusual circumstances.

A slug of liquid hydrocarbons having solvent properties such as condensate or diesel fuel is pushed through the pipeline between two stiff rubber scraper pigs at a constant speed by an inert gas such as nitrogen. Other additives or treatment chemicals may be added if desired. As a rule of thumb, the volume should be calculated to maintain a minimum pipe wall contact time by the fluid ranging from five to ten minutes (or longer), depending on the effectiveness of the initial in-service cleaning process.

For lines having encrusted or high paraffin build-up, an additional volume of solvent preceding the first pig can be considered. All contact times should be increased for excessive lengths of line as the solvent may become saturated with hydrocarbons before completion of the run. The following diagram illustrates the pipeline sequence of movement. At the endpoint, the solvent and hydrocarbons are pushed into another section of pipeline or collected in a containment tank for disposal. A repeat run of the pig train described above should be conducted if there are any indications of liquids or contaminants remaining on the pipe wall in excess of the established cleanliness criteria. The effectiveness of the cleaning process can be gauged by either obtaining samples of the solvent near the tail end of the passing batch, at approximate 25 km intervals, or analyzing the samples for hydrocarbon content, or by monitoring the quality and quantity of the solvent hydrocarbons expelled from the line and comparing it with that injected.

Appendix B – Pipeline System Maps[12]

B.1 Natural Gas Pipelines

Figure B1: Natural gas pipelines (CEPA - Maps: Natural Gas Pipelines, Liquids Pipelines)

[12] Reproduced from (CEPA - Maps: Natural Gas Pipelines, Liquids Pipelines)

B.2 Liquids Pipelines

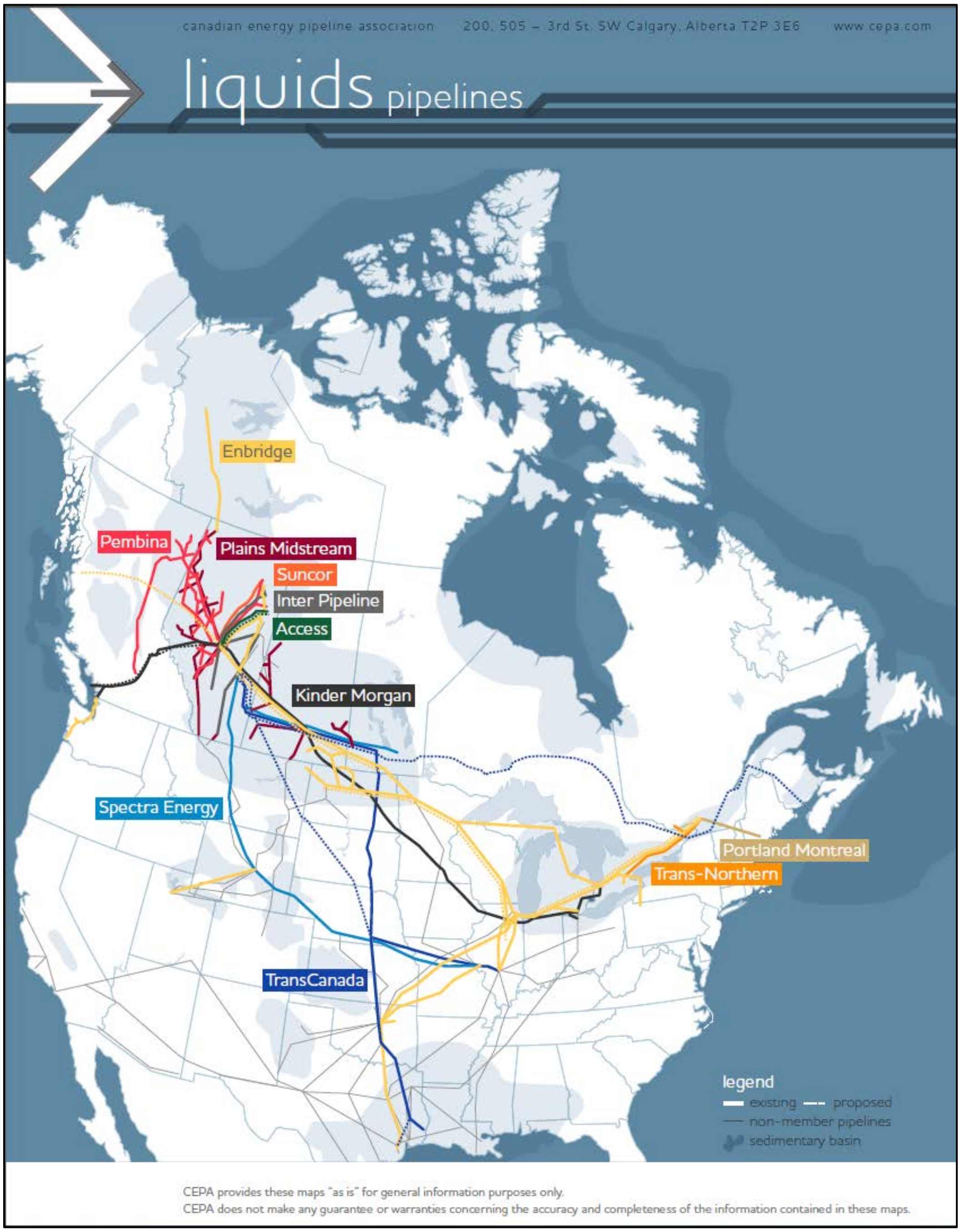

Figure B2: Liquid pipelines (CEPA - Maps: Natural Gas Pipelines, Liquids Pipelines)

Appendix C – Potential Contaminants from Abandoned Oil and Gas Pipelines[13]

Table C1: Summary of Substances Which May be Released by Abandoned Oil and Gas Pipelines

1. Produced Components of Oil and Gas	
alkanes; cycloalkanes; monoaromatic hydrocarbons; polyaromatic hydrocarbons; polyaromatic sulphonated hydrocarbons; hydrogen; helium	
ions: calcium, sodium, chloride, carbonate, sulphate	
sour gases: hydrogen sulphide; carbon dioxide; carbon disulphide; carbonyl sulphide; mercaptans, including ethylated and methylated forms	
produced metals: Hg, Ni, V, Cr, As	
radioactive elements (NORMs): barium, strontium, radium, uranium, radon decay-products: lead 210, bismuth 210, polonium 210	
2. Deposited Scales	
corrosion scale: FeS, FeO, $FeCO_3$; hardness scale: $CaCO_3$, $CaSO_4$, $BaSO_4$	
asphaltenes, waxes, gums, resins, paraffins, naphthenes, bitumens	
3. Treatment Chemicals	
Chemical (s)	Application
hydrochloric acid, with phosphate-type inhibitor and sodium or ammonium hydroxide neutralizer	removal and control of calcium carbonate-type scale
xylene, toluene	removal of asphaltinic and waxy type scale
kerosene	diluent for batched corrosion inhibitor
sodium dichromate, hexametaphosphate, silicates	corrosion inhibitors used prior to mid-1960s
quaternized amines	current continuous corrosion inhibitors
sodium sulphite	historically used oxygen scavenger
ammonium bisulphite	current oxygen scavenger
Sodium Hypochloride	aerobic biocide
Cocodiamine, Glutaraldehyde	anaerobic biocide
Cu, Hg based compounds	algicides
PCBs, triarylphosphates, terphenyls	compressor coolants and lubricants
glycols (propylene; mono, di, and tri ethylene)	dehydration units and compressor coolants
brine and alcohol based coolants	compressor coolants
Pb, Cu, Zn based compounds	≤60 weight% of thread compounds
Diesel-based emulsifiers	slurry promotion in multi-phase lines
Methanol	pressure testing; hydrate removal
4. Pipe Body and Metal Wear	
iron (97 to 99% by weight), manganese (0.5 to 2.0% by weight), copper, nickel, molybdenum,	
niobium (toughening agent); vanadium, titanium (strength at low temperatures); copper, zinc, chromium, cadmium (compressor wear); aluminum (primary component of some high pressure gas transmission lines)	
welding rod: carbon steel, stainless steel, cast iron, copper, brazing copper-silicon with phosphor-bronze, brazing naval bronze with manganese-bronze, silver solder, soft solder (primarily lead), and wrought iron	
sacrifical anodes: lead, chromium, iron, magnesium, tungsten, aluminum, zinc	
impressed current cathodic protection system anodes: scrap steel, scrap iron, carbon	
5. Pipe Coatings and Their Degradation Products	
coal tar: toluene, xylene, anthracene, and other PAHs	
blown bitumen (asphalt), fibreglass wrap, asbestos felt	
coal tar enamel, glass or asbestos outer wrap	
"yellow jacket": rubberized asphalt mastic, high density polyethylene, carbon black	
fusion bonded epoxy: bisphenol, epichlorhydrin resin, amine or anhydride based hardener, chalk, silica	
dioctyl thalate plasticizer in older polyethylene	
"blue jacket": chromate pretreatment, epoxy resin, adhesive, high density polyethylene	
organic-based biocides (unidentified type)	
primer-type adhesives: butyl rubber based elastomer polymeric resin: heptane, naphta, 1,1,1 trichloroethane	

[13] Reproduced from (Thorne, Basso, & Dhol, 1996)